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Mineral Technology 14

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

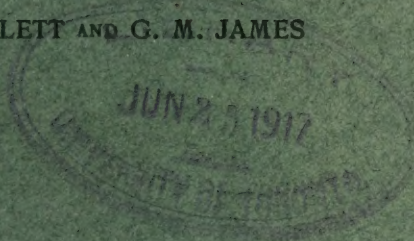
BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

MELTING ALUMINUM CHIPS

BY

H. W. GILLET AND G. M. JAMES



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MELTING ALUMINUM CHIPS.

By H. W. GILLETT and G. M. JAMES.

INTRODUCTION.

In its work on mineral wastes the Bureau of Mines is studying losses in the melting of nonferrous metals and alloys. The greatest of these losses is that of zinc through volatilization in brass melting, but another and considerable loss is that of aluminum and its alloys in the melting of finely divided material.

In order to get some idea of the magnitude of the loss in melting aluminum scrap and to find out what methods of melting were used information was gathered in regard to present practice; also experiments were conducted to obtain some data on the relative merits of different methods. As the experiments could be made on a laboratory scale only, they were not expected to solve the problem entirely, the object in making them being rather—by indicating which methods were of greater promise—to narrow the field over which large-scale tests and comparisons need be made by those commercially interested in the problem of melting scrap aluminum.

NATURE OF SCRAP ALUMINUM.

Scrap aluminum may be produced in the fabrication of sheet aluminum into various objects, such as cooking utensils, camera frames, and various ornamental goods, yielding sheet clippings or punchings, in the machining of aluminum castings for automobiles, motor boats, cooking utensils, vacuum cleaners, meter cases, and the multitudinous other articles in which cast aluminum is used, yielding borings or chips, or in the foundry, in the chipping and grinding of rough castings, and in the recovery of buttons of metal from foundry sweepings, or from the dross skimmed from the melting pots.

CLIPPINGS AND PUNCHINGS.

Sheet clippings and punchings do not, as a rule, show a very great melting loss, for they are normally kept clean and are usually not excessively small nor thin, and may without the use of very great pressure be "cabbaged" or pressed into brick-like bundles, which

are considered almost as valuable for foundry use as ingot metal, particularly as it is necessary, in order to obtain good rolling qualities, to use purer metal for sheet than is sold for casting purposes. "Hard-sheet" aluminum, containing upwards of 1 per cent of manganese, must of course be used with due consideration of the content of the alloyed metal.

SCRAP WIRE AND CABLE.

Scrap wire and cable is a still purer aluminum than unalloyed sheet aluminum, as the very purest metal attainable is required for high electrical conductivity. Bare wire and cable is a desirable form of scrap, but insulated wire would be hard to handle in remelting. On account of the growing use of aluminum wire of small diameter, that is electrolytically insulated with a film of aluminum oxide,^a this wire will at some future time form a variety of scrap that will be more or less difficult to remelt.

CASTINGS, CHIPS, AND BORINGS.

The great bulk of the scrap aluminum met with at present consists of old castings and of chips and borings obtained in machining castings. Melting down old castings presents no difficulty, as the loss is scarcely greater than with ingot metal. The chips and borings, however, give much trouble, and form the main problem in regard to metal losses in remelting scrap aluminum.

As at least 95 per cent of all cast-aluminum alloys is used for automobile engine beds or crank cases, gear cases, transmission cases, footboards, bodies, steering-wheel spiders, intake and outlet manifolds, hub caps, and miscellaneous trimmings and fittings, chips from a motor-car manufacturing plant may be regarded as typical.

The drill presses and milling machines used on aluminum castings run either with a light cutting oil, kerosene being often used, or with cutting lubricants of the general type of emulsions of oil in a soap solution. The emulsions seem to be coming into increasing use.

If the chips stand in the air while wet with such aqueous solutions, that is, if the solution is not drained off at once, they become superficially oxidized and caked together.

The chips become covered with whatever lubricant is used, soaking it up like a sponge. If they fall on the floor and are swept up without due care to keep them separate from the floor dust, the dust sticks to the oily or moist borings.

If the machining of iron, steel, brass, or white metal is done near by, chips of those metals are likely to become mixed with the aluminum chips. It is the exception and not the rule to find aluminum chips

^a Skinner, C. E., and Chubb, L. W., The electrolytic insulation of aluminum wire: Trans. Am. Electrochem. Soc., vol. 26, 1914, p. 137.

that are not contaminated with a few per cent of iron chips. The iron necessitates passing the chips over a magnetic separator. On account of the more curly form of chips from aluminum than from most commercial brasses and bronzes, it is harder to effect a complete separation of the iron, particularly from damp or oily chips.

The chips may go to the aluminum foundry of the automobile plant, if it makes its own aluminum castings, or may be sent to various refiners, who either buy the chips outright or refine them into ingots, make a smelting charge, and return the ingots obtained, or the chips may be sold in small lots to some small dealer in scrap metal, who adds them to various other chips until he has enough to melt down himself or sell to a larger operator.

Some of the larger operators state that it is apparently difficult for some of the small junk dealers to resist the temptation to add road dust, foundry sweepings, or other fine dirt to the borings, as 10 per cent or more will readily stick to oily borings and be scarcely detectable even on close inspection.

The size and thickness of the chips depends on the depth of the roughing and finishing cuts. The thickness commonly runs between 0.005 and 0.02 inch.

RECOVERY ON SCRAP ALUMINUM.

Foundry wastes, such as spillings recovered in floor sweepings, small fins that work their way into core prints, chippings from the trimming room, and dust from the emery grinders, are all badly contaminated with dirt. The larger pieces are picked out by hand and the rest concentrated by tumbling dry in a stream of air, or in a wet tumbling barrel. The scum of oxide, dirt, and metal that is skimmed from the melting pots is generally remelted in the foundry, usually with the use of sal ammoniac or zinc chloride, and the dross from this remelting is thrown away, sold to a refiner, or dropped into water as soon as skimmed off, and then subjected to wet tumbling.

In melting fine material, such as borings or chips, fine shot from foundry wastes, and dust from grinding wheels, all heavy scrap being excluded, the recovery as ingot metal runs from 40 to 90 per cent of the metal content, the proportion recovered varying with the size and cleanness of the material and with the facilities, experience, and method of the melter.

It is very doubtful if any but the largest and most experienced refiners average more than 65 per cent recovery from the ordinary dirt-laden borings of commerce. One firm organized solely to refine borings to ingot suspended operations after a few months, and another firm has run its aluminum-refining department only intermittently, finding that when aluminum was scarce it was better to stop refining borings because their price rose above that at which a profit could be

made with the percentage of recovery obtained. At such times the borings go to small refiners, or to foundries that refine the borings separately or add them to the regular melts. In many cases no accurate records of costs are kept by such plants, and the operators may be refining at a considerable loss without knowing it.

A prominent aluminum founder states that with pure aluminum selling at 25 cents per pound and copper at 15 cents, the most common casting alloy, "No. 12," containing 8 per cent copper, would sell in new ingot for about $24\frac{1}{2}$ cents, whereas good No. 12 borings would command about $12\frac{1}{2}$ cents and the ingot made from the borings would sell at about 22 cents. If the cost of refining, including the cost of fuel, labor, overhead charges, etc., is arbitrarily assumed to be 1 cent per pound of ingot produced, it will be seen that with a 50 per cent recovery on the gross weight of borings bought, the cost of producing a pound of ingot would be 25 cents for metal and 1 cent for refining charges, or 26 cents, which, with metal selling at 22 cents, would result in a loss of 4 cents per pound of ingot, whereas with a 70 per cent recovery the cost would be about 20 cents, netting a profit of 2 cents per pound. With a 60 per cent recovery there would be a slight loss, whereas with an 80 per cent recovery the profit would be over 5 cents per pound. It is assumed that the same price, $12\frac{1}{2}$ cents, is paid for borings from which only 50 per cent of metal is recovered as for those yielding 80 per cent.

If it be assumed that the average recovery from chips and foundry waste is 65 to 70 per cent, on the metallic basis, and if, as is shown later, borings kept perfectly clean and properly melted will give 90 to 95 per cent recovery, then 20 to 30 per cent of the aluminum that is machined off castings is unnecessarily lost.

The probable amount of aluminum castings used in motor-car construction from July 1, 1914, to July 1, 1915, has been estimated by the general manager of a firm of aluminum founders, whose production alone is over half that amount, to be between 20,000,000 and 25,000,000 pounds. Addition of heavy export orders to the increasing domestic demand will undoubtedly cause the amount used from July 1, 1915, to July 1, 1916, to exceed 25,000,000 pounds.

The percentage machined off from a rough aluminum casting in the finishing process seems, from data obtained by the writer, to average about 15 per cent, a figure which is much higher than was estimated offhand by several people connected with the automobile and aluminum casting industries, whose guesses averaged 3 to 4 per cent. The writer's result was reached by weighing rough and finished castings at an automobile plant making a car in the \$700 to \$800 class, and by weighing rough and finished castings made for various other motor-car manufacturers at an aluminum foundry, with the following results:

Proportion of metal machined off in finishing aluminum castings for motor cars.

Casting.	Weight of rough casting.	Weight of finished casting.	Percentage of metal machined off.
	<i>Pounds.</i>	<i>Pounds.</i>	
Gear and transmission case.....	28.50	24.50	14
Small double-flanged exhaust elbows.....	.42	.35	15
Intake pipe for 8-cylinder motor.....	5.00	4.80	4
Gear case for small motor.....	8.90	7.00	21
Gear case for very small motor.....	1.58	1.50	5
Crank case for 8-cylinder motor.....	94.00	80.00	14.5

As crank cases and transmission cases make up the bulk of the weight of aluminum castings in a car, the values obtained from them will have more effect on the total than those obtained from the smaller castings.

The results of this tabulation, which indicate that 15 per cent was machined off, were so at variance with the estimates cited that the matter was taken up with the makers of a car in the \$2,000 class, who state that on that car there are used 47 aluminum parts which are machined, the total weight of the rough castings used per car being 166.19 pounds. The loss per car in chips is 25.15 pounds, or 15.1 per cent. The weights were taken on the average of a number of like parts, in some cases as many as 50 being weighed. On the basis of 15 per cent of metal machined off, the yearly production of chips from aluminum castings in the United States will then run between 3,000,000 and 3,750,000 pounds. If 20 to 30 per cent of this amount is unnecessarily lost, then 600,000 to 1,125,000 pounds of aluminum alloys worth 16 to 25 cents per pound, based on the average market quotations for the last few years, is lost, or, as these figures take no account of the loss in running down foundry wastes, it may be estimated that in all metal worth approximately \$200,000 at average prices for aluminum, is lost each year in the United States through the low recovery in melting down aluminum borings and foundry waste. At the abnormal price of aluminum in 1916 this figure would be doubled or trebled.

This estimate is not too high, as the United States Geological Survey states ^a that in 1913 2,198 tons of secondary aluminum and 2,456 tons of secondary aluminum alloys (90 per cent of the latter being "No. 12" alloy, containing 92 per cent aluminum and 8 per cent copper) were recovered, mostly from aluminum clippings and borings, the whole having a value of \$2,199,480. The total consumption of aluminum in the United States in 1913 was 36,190 short tons.^b

^a Phalen, W. C., Bauxite and aluminum: Mineral Resources of the United States for 1913, U. S. Geol. Survey, 1914, p. 16.

^b Phalen, W. C., *Loc. cit.*

If the pure aluminum, mostly from clippings, which give low loss on melting, be entirely disregarded and the alloys only be considered, and if it be further assumed that only two-thirds of the quantity of alloys came from borings, there would be about 3,250,000 pounds of secondary aluminum alloys recovered. If this figure represents a 70 per cent recovery of the original metal content in the borings, which is as high as is probable, and if a 90 per cent recovery is possible then two-sevenths of 3,250,000 pounds, or over 1,000,000 pounds, was lost in melting. The average value of the secondary pure aluminum and alloys was about $23\frac{1}{2}$ cents per pound in 1913, according to the figures of the Geological Survey. If the alloy is assumed to be worth 20 cents, the value of the lost metal figures to about \$200,000 for 1913.

The 1914 figures ^a show 2,791 tons of secondary aluminum and 1,731 tons of recovered aluminum contained in alloys, having a total value of \$1,673,140, or an average of $18\frac{1}{2}$ cents per pound. It is stated that the greater part of the secondary aluminum was recovered from clippings and borings. Pure aluminum borings are not common, and as refineries commonly term borings from aluminum alloys "aluminum borings," their reports may not have made a clear distinction between pure and alloyed metal.

Although figures for 1914 showed a decrease in amount and value of recovered aluminum alloys as compared with 1913, the high average price of aluminum in 1915 will bring the values of the losses for 1915 to about \$300,000, as in the fall of 1915 the price of aluminum rose to about three times the prices quoted in 1914 and in the spring of 1915.

There are, of course, other possible uses for aluminum alloy chips than as a source for the recovery of ingot metal. Their use for the manufacture of aluminum paint at once suggests itself, but it is doubtful if all alloys of aluminum are malleable enough to produce the very thin flat flakes required in aluminum paint. Pure aluminum scrap could doubtless be so used. One automobile firm, during the period of unusually high prices for aluminum in 1915 and 1916, was forced to find a substitute for the aluminum paint previously used on its motors and found one in finely crushed ferrosilicon. This firm also reported that it could, in this period, obtain a higher price for its aluminum chips from a chemical company than it could from the metal refiners. The chips are evidently used in the preparation of anhydrous aluminum chloride, to be used as a condensing agent in the manufacture of dyes.

^a Phalen, W. C., The production of bauxite and aluminum: Mineral Resources of the United States for 1914, U. S. Geol. Survey, 1915, pp. 183-209.

METHODS OF MELTING ADVOCATED IN THE LITERATURE.

Various methods of melting down chips are suggested in the periodical and patent literature. One of the earliest comments ^a on the subject is as follows:

ADDING SCRAP TO MOLTEN METAL.

We recently had an inquiry for a method of recovering the aluminum from the skimmings taken from the casting ladle. The company making the inquiry is in the aluminum casting business, the parts being mostly for automobile work. One essential was that the recovered metal must be of such degree of purity that it could be used over again for casting. As the quantity of skimmings is large, the waste at present going on is considerable.

There is no way of accomplishing this in a commercial manner except by putting the skimmings into the reduction pots, and even that is objectionable with a great many kinds of alloy skimmings, particularly those containing zinc. It is extremely difficult to get finely divided particles of aluminum to agglomerate, even when fused, owing to the difficulty of breaking the skin which covers each particle. The only method by which it was ever done is that recited by De Ville—namely, melting finely divided metal by using a double chloride of sodium and aluminum, which acts as a flux and permits some of the finely divided aluminum to be made into a button. This operation is, however, so difficult and so unusual that the expense of it is considerably more than the value of the metal recovered.

Sperry ^b states "The best way to melt aluminum scrap, such as sheet or chips, is to have a pot of molten aluminum at low red heat and then to add the scrap to it, pushing it down at once under the surface, so that it is not exposed to the air at all. In this manner there is no oxidation of the aluminum and it can be melted with the minimum waste. The scrap will dissolve in the molten aluminum, and this is an ideal condition." He also states ^c that the chips should be added in small quantities at a time to already molten metal with immediate stirring, and the pot fluxed at the end of the melt with a little zinc chloride.

Vickers ^d suggests practically the same method. Still another description ^e of this general method follows:

Question.—We have several barrels of aluminum turnings and borings and would like to know the best method of converting this material into pig form. We understand that under certain conditions of melting a considerable loss of aluminum results.

Answer.—The melting of finely divided metals entails considerable work, and furthermore, the material must be handled in a manner which will prevent undue oxidation. The best way to accomplish this is to dissolve the finer metal in a bath of molten metal. A large crucible should be used and the molten metal should be obtained by melting ingots or other bulky stock. In the case of aluminum, the bath should be

^a Editorial, Recovery of aluminum from skimmings: *Metal Ind.*, vol. 5, 1907, p. 100.

^b Sperry, E. S., Questions and answers: *Brass World*, vol. 9, 1913, p. 296.

^c Sperry, E. S., Remelting of aluminum chips or borings: *Brass World*, vol. 6, 1910, p. 278; *Jour. Inst. Metals*, vol. 5, 1911, p. 332.

^d Vickers, C., How to melt aluminum turnings or borings: *Foundry*, vol. 41, 1913, pp. 119, 120.

^e Editorial, Recovery of aluminum turnings and borings, problems of the brass founder: *Foundry*, vol. 43, May, 1915, p. 195.

raised to a temperature not above red heat. Charge as many borings at a time as the bath will dissolve, but do not leave any of the borings on top of the bath in a solid state. These should be stirred into the molten metal. Inasmuch as the bath increases with each charge of borings, it will dissolve more each time that additions are made. As the borings will cool the bath, the furnace should be closed from time to time, the metal again heated to redness, when more borings can be added, and this process can be continued alternately until the pot is full. At this stage the metal is cast into ingots, but sufficient should be left in the pot to form another bath. If the mush-like dross gathers on the surface of the metal, add a small piece of fused zinc chloride and stir it on the surface. This will liberate the metal from the dross, which will form a cover for the aluminum. The metal should be skimmed before casting into ingots. Incidentally, this dross is of no value.

In doing this work the borings should be passed through a magnetic separator to remove the iron, and under no conditions should the bath of molten metal be heated above redness at any time, as otherwise the aluminum will attack the silica in the crucible and the metal will contain black specks.

A similar method in which turnings are to be charged into a "heel" of molten metal, but a reverberatory furnace used, not a crucible, has been advocated,^a though no mention is made of stirring or the use of any flux.

Echevarri^b says, "Scrap can be remelted by submerging in the molten metal, the loss being only 2 to 3 per cent." This statement evidently refers to heavy scrap.

Coulson^c has recently described a puddling method, commercially used for the recovery of turnings from an aluminum alloy with 5 to 10 per cent of magnesium, as well as considerable experimental work on the problem. Previous to the experimental work, cryolite had been used as a flux, the recovery with clean turnings varying from 60 to 90 per cent on clean material. In the experiments, turnings were melted in air-tight, electrically heated furnaces, in which the air could be displaced by reducing gases, such as hydrogen. Even in such a nonoxidizing atmosphere 10 per cent was lost, and nitrides were still formed, indicating that air was occluded in the borings. Then the turnings were boiled in a 4 per cent salt solution to displace occluded air and wash off dirt. These treated borings, melted under hydrogen, still gave 8 per cent loss. Melting under hydrogen was considered impractical for commercial work, so melting in open crucibles was tried. The borings were washed in benzine and then boiled in a salt solution. The damp borings were fed into a hot crucible containing a small "heel" of molten metal, and each addition thoroughly puddled until the mass became uniformly viscous. After all the borings were in, the charge was allowed to stand until the dross had risen, when the clean metal was poured from beneath the dross, or tapped off from a hole in the bottom of the crucible.

^a F. H. H., Refining scrap: Foundry Trade Jour., vol. 14, 1914, p. 29.

^b Echevarri, J. T. W., Aluminum and some of its uses: Jour. Inst. Metals, vol. 1, 1909, p. 128.

^c Coulson, J., Reclamation of magnalium from turnings: Trans. Am. Inst. Metals, vol. 9, 1915.

Calcium chloride was then stirred into the dross. If the temperature rose through thermit action, powdered cryolite was stirred in. The metal separated from the dross was then poured or tapped. The loss by this method averaged 6 per cent for small melts, and with 200-pound melts of clean material the loss has been as low as 1 per cent.

It is stated that the addition of 1 per cent of calcium or 0.5 per cent of calcium aluminum silicide restores the reclaimed metal to its original physical state as shown by tensile tests.

Such additions should be made with caution, since for some purposes the presence of alkali or alkaline earth metals is detrimental, and in the production of aluminum every effort is made to keep them out, as they are considered highly undesirable impurities. Le Chatelier^a has shown that calcium aluminum alloys are liable to disintegrate, apparently spontaneously.

Puddling methods were used by De Ville on a small scale in 1859, and his directions, as quoted by Richards,^b quite closely describe the puddling method in use to-day. These directions are as follows:

When it is desired to melt pieces together, they can be united by agitating the crucible or compressing the mass with a well-cleaned cylindrical bar of iron. (Clippings, filings, etc., are melted thus: Heat the divided metal to as low a heat as possible—just sufficient to melt it. The oil and organic matter will burn, leaving a cinder, which hinders the reunion of the metal if the mass is not pressed firmly with the iron bar.

USE OF FLUXES IN MELTING ALUMINUM SCRAP.

Zinc chloride (ZnCl_2) is often used as a flux in running down chips and skimmings, as well as in ordinary melting, it being claimed that the zinc chloride aids the separation of the metal from the dross so that instead of a pasty mass of metal plus dross only a dry, crumbly dross is taken off.^c The value or uselessness of zinc chloride as a flux for ordinary melting is a matter of contention among aluminum founders. Lane^d found that 0.015 per cent of zinc was taken up by an aluminum alloy on one melting and 0.085 per cent after the eighth remelt, zinc-chloride flux being used each time. He suggests that some of the zinc chloride may be decomposed by the heat and part of the zinc may alloy with the aluminum, the nascent chlorine being the active agent of the flux.

Micks^e states—

The flux that has given the best results in aluminum is chloride of zinc. The zinc combines with the oxygen which is taken up from the aluminum oxide and forms zinc

^a Le Chatelier, H., Alterability of aluminum: *Compt. rend.*, 7, 152, 1911, p. 659. *Chem. Abs.*, vol. 5, 1911, p. 1898.

^b Richards, J. W., *Aluminum, its properties, metallurgy, and alloys*, 1890 pp. 202, 247.

^c Anon., Use of zinc chloride in melting aluminum: *Jour. Inst. Metals*, vol. 2, 1909, p. 320.

^d Lane, H. M., Use of magnesium in desoxidizing aluminum alloys: *Trans. Am. Brass Founders' Assn.*, vol. 4, 1910, p. 101; *Castings*, vol. 7, 1911, p. 163.

^e Micks, R., *Furnace practice in the brass foundry*: *Brass World*, vol. 11, 1915, p. 150.

oxide, which is then skimmed off together with the aluminum chloride that is also formed in the reaction when the flux is added. The best time to add this flux is after the melting is completed; the surface of the molten metal is then covered with a mass of dross, but when the chloride of zinc is dropped on it in small pieces it will become clear as soon as enough of the flux has been added.

Lane considers that magnesium is a deoxidizer of aluminum. However, Matignon^a reports the reduction of magnesium oxide by aluminum. It is also stated^b that although from thermochemical data both magnesium and calcium should reduce aluminum oxide, magnesium does not act as strongly in a thermit mixture as aluminum, and that it probably is not a deoxidizer for aluminum. It was thought that calcium was reduced by aluminum when calcium chloride was used as a flux, and the statement was made that the only value of calcium chloride or zinc chloride as a flux is in disentangling the aluminum from the dross.

Another flux recommended^c is anhydrous aluminum chloride (AlCl_3), the claim being made that by the use of a small amount of aluminum chloride a recovery of 50 to 70 per cent could be obtained from chips, which without it yielded only 30 per cent.

Another flux recommended consists of sodium carbonate 10 parts, potassium carbonate 2 parts, cryolite 2 parts, and borax 1 part, to be used in the proportion of $1\frac{1}{2}$ pounds per 100 pounds of chips.^d

Borax is suggested by Mellen^e as a flux to dissolve oxides of aluminum.

However, Richards^f states that aluminum melted under borax is rapidly dissolved, an aluminum borate being formed.

Weber^g suggests the use of fluorides of zinc, copper, or nickel, mixed with alkali fluorides. The aluminum reduces the fluoride of the heavy metal used, the zinc, copper, or nickel alloying with the aluminum and forming an equivalent amount of aluminum fluoride. The mixture of aluminum fluoride and alkali fluorides then acts as a slag to dissolve the aluminum oxide. Weber also suggests a mixture of zinc chloride and sodium fluoride.

Jones^h suggests a flux of equal parts of lithium chloride, potassium chloride, and sodium fluoride for use in welding aluminum.

Schoopⁱ emphasizes the difficulty of breaking through the thin surface film of oxide in welding aluminum so as to make the fluid metal, beneath the films of the two pieces to be welded, unite, and

^a Matignon, C., Reduction of magnesia by aluminum: *Compt. rend.*, t. 156, 1913, p. 1157; *Jour. Soc. Chem. Ind.*, vol. 32, 1913, p. 491.

^b Anon., Oxidation of aluminum: *Foundry*, vol. 37, 1910, p. 225.

^c Anon., The fusion of aluminum chips: *Jour. Mines Met.*, t. 1, 1912, p. 7; *Chem. Abs.*, vol. 6, 1912, p. 2223; *Brass World*, vol. 9, 1913, p. 365.

^d Anon., Melting aluminum chips: *Castings*, vol. 38, 1910, p. 78.

^e Mellen, J. G., and Mellen, W. F., U. S. Patent 982218, Jan. 17, 1911.

^f Richards, J. W., Aluminum, its properties, metallurgy, and alloys, 1890, p. 81.

^g Weber, H., Process for melting scrap aluminum or alloys high in the metal: German Patent 242347, Dec. 30, 1910; *Jour. Soc. Chem. Ind.*, vol. 31, 1912, p. 237; *Chem. Abs.*, vol. 6, 1912, p. 2063.

^h Jones, J. L., Shop problems—fluxing: *Metal Ind.*, vol. 11, 1913, p. 528.

ⁱ Schoop, M. V., Autogenous welding of aluminum: *Electrochem. and Met. Ind.*, vol. 7, 1909, p. 151.

states that he has tried borax, glass, and other substances to exclude the air, but found that a flux which would dissolve the oxide was needed. He then tried potassium pyrosulphate and many other substances as fluxes to dissolve the oxide, but found a satisfactory solution of the problem only in the use of alkali chlorides. In his patents Schoop^a mentions a mixture consisting of 60 parts potassium chloride, 20 parts lithium chloride, 12 parts sodium chloride, 8 parts potassium sulphate. In a later patent^b he substitutes cryolite for the potassium sulphate, and in another,^c he says, "Experiments have shown that the said defects may be completely avoided by adding fluorides—for example, fluorides of calcium, potassium, or boron to the mixture of chlorides of alkali metals. By means of the improved flux it is possible also to melt down or fuse together in crucibles small and large scraps of aluminum in the shape of castings, sheets, wires, or other objects."

Morrison^d speaks well of such a flux for welding, as does Seligman.^e Other welding fluxes have been suggested, Thaulow^f recommending 96 parts of borax and 4 parts of sodium bisulphate.

Pannell^g gives the composition of various fluxes for use in welding, as follows:

Composition of various fluxes for use in welding.

Flux No.	Constituent.							
	Sodium chloride.	Potassium chloride.	Lithium chloride.	Potassium fluoride.	Sodium fluoride.	Sodium bisulphate.	Potassium bisulphate.	Cryolite.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1.....	30.0	45.0	15.0	7.0		3.0		
2.....		33.0	33.0		33.0			
3.....	12.5	62.5	20.8				4.0	
4.....	16.0	79.0					5.0	
5.....	17.0	83.0						
6.....	6.5	56.0	23.5			4.0		10.0

It is seen that these are all mixtures of alkali chloride high in the low-melting potassium and lithium chlorides, with or without the addition of fluorides or bisulphates.

Other processes are based on the theory that as aluminum is readily oxidizable, the melting should take place in the absence of air. Mellen^h patented a vacuum furnace in which it is claimed that aluminum clippings, turnings, and filings ordinarily melted with a loss of 10 to 40 per cent may be melted with a loss of only 0.5 to 5 per cent.

^a Schoop, M. V., U. S. Patent 922523, May 25, 1909; English Patent 24096, Oct. 31, 1907; French Patent 374089, Jan. 30, 1907.

^b Schoop, M. V., U. S. Patent 943164, Dec. 14, 1909.

^c Schoop, M. V., English Patent 24283, Nov. 2, 1907.

^d Morrison, W. M., In discussion: Jour. Inst. Met., (British) vol. 1, 1909, p. 150.

^e Seligman, R., The welding of aluminum; Jour. Inst. Met. (British), vol. 2, 1909, p. 281.

^f Thaulow, E., U. S. Patent 1139923, Mar. 4, 1914; Brass World, vol. 11, 1915, p. 181.

^g Pannell, E. V., Recent developments in aluminum; some notes on autogenous welding: Trans. Am. Inst. Metals, vol. 9, 1915. Advance copy, p. 17.

^h Mellen, G., U. S. Patent 1120732, Dec. 15, 1914.

One inventor, according to parties to whom the invention was offered for \$100,000, had a plan to melt aluminum borings by melting in retorts similar to those used in zinc smelting and passing in steam when it was desired to check the heating and stop oxidation by air. A recovery of 85 per cent was claimed. No further details are available.

Zavelberg ^a suggests for zinc smelting or the recovery of other readily oxidizable metals heating the furnace, discontinuing the heating, charging and closing the furnace, and doing the melting by the stored heat. Practically the same method has been used in the melting of aluminum-magnesium alloys for casting purposes in a tilting open-flame oil furnace, though it does not seem to have been tried on borings.

Richards ^b says:

Fused common salt is used as a flux for aluminum. Fluorspar makes a good flux for the metal, especially in connection with cryolite or common salt, and possesses the property of dissolving the aluminum oxide with which the metal may be contaminated and which, by incrusting small globules, hinders their reunion to a button.

Various fluxes have been used in melting aluminum without having been especially mentioned in connection with borings.

Guertler ^c mentions a mixture of sodium and potassium chlorides.

Zinc chloride, a mixture of sal-ammoniac (ammonium chloride) and common salt, as well as saltpeter (potassium nitrate) are all mentioned. ^d

Schultz ^e also reports favorably on the use of saltpeter in melting aluminum alloys to get sound castings. It seems remarkable that the addition of so strong an oxidizing agent to so readily oxidizable a metal should be beneficial, and the most plausible explanation is that the gas given off by the decomposition of the saltpeter stirs the metal and is carried off with the other and harmful gases previously dissolved in the metal. Saltpeter has not been advocated for use on chips. Sal ammoniac alone is also used. ^f

Gleason ^g melts aluminum under a flux composed of 3 parts fluorspar and 1 part anhydrous boric acid. Mellen ^h uses a flux consisting of salt and sulphur.

Desch ⁱ mentions borax, which melts at about 650° C., and anhydrous carnallite (equimolecular amounts of potassium and magnesium chlorides), which melts at about 450° C., as forming suit-

^a Zavelberg, A., U. S. Patent 1136304; German Patents 226257, Feb. 23, 1908; 276364, Aug. 6, 1913; Chem. Abs. vol. 9, 1915, p. 594.

^b Richards, J. W., *Aluminum its properties, metallurgy, and alloys*, 1890, p. 80.

^c Guertler, W., *Metallographie*, Bd. 2, Heft 1, 1913, p. 39.

^d Editorial, Flux for aluminum alloy—problems of the brass foundry: *Foundry*, vol. 41, 1913, p. 420.

^e Schultz, F., In discussion: *Trans. Am. Inst. Metals*, vol. 8, 1914, p. 132.

^f Carritto, J. P., Making McAdamite metal; *Foundry*, vol. 41, 1913, p. 421.

^g Gleason, E. D., U. S. Patent 1076973, Oct. 28, 1913.

^h Mellen, G., U. S. Patent 1092935, Apr. 14, 1914.

ⁱ Desch, C. H., *Metallography*, 1910, p. 106.

able protecting layers for low-melting alloys. The melting point of the eutectic mixture ($2\text{KCl}.\text{LiCl}$) of potassium and lithium chlorides is given ^a as 350°C . and that of the lowest melting mixture of NaCl and LiCl (27 per cent by molecular weight of NaCl , 73 per cent LiCl) as 550°C .

Burgess ^b gives the melting point of an equimolecular mixture of NaCl and KCl as about 650°C .

A flux recently put on the market at 25 cents per pound is said by its introducers to act as a molten cover to protect the metal from the air and also as a flux to dissolve impurities from the melt. The directions state that 1 pound of flux should be used to 250 pounds of metal and scattered over the cold metal as much as possible, so that the metal will be protected while being heated. After all the metal is melted it should be stirred with an iron rod, when the flux will come to the top, as it melts below the melting point of aluminum and rises as soon as the metal is melted. For running down scrap or skimmings, the flux is to be used in the same way, but more must be used than when clean metal is melted, the amount depending on the content of impurities.

Cryolite (sodium aluminum fluoride) is sometimes used as a flux in running down borings, as this is the main constituent of the electrolyte used in the reduction of aluminum, and aluminum oxide is quite soluble in it. The melting point of cryolite (about 980°C .) is high for the purpose, and various substances might be added to lower it.

In the direct testimony of A. H. Cowles before the Circuit Court of the Northern District of Ohio, May 6, 1899, C. M. Hall is quoted as stating that KCl and NaCl fluxes do not dissolve oxides and other dirt from aluminum, but fluorides do.^c

Wright ^d states that the electrolyte used in the production of aluminum is composed of cryolite ($\text{AlF}_3.\text{NaF}$), aluminum fluoride, and fluorspar in the proportions of about 16 per cent CaF_2 , 28 per cent ($\text{AlF}_3.\text{NaF}$), 56 per cent AlF_3 , the AlF_3 being made by treating bauxite with HF . This is evidently taken from the United States patent 400667 of C. M. Hall, whose various patents Nos. 400665, 400666, 400667, and 400766 cover AlF_3 plus fluorides of Na , K , Li , and Ca .

Pascal ^e intimates that cryolite and fluorspar are both used in the electrolyte. He finds that the eutectic mixture of CaF_2 and Al_2O_3

^a Zemeuzny, S., and Rambach, F., *Schmelzen des alkali Chloride*: Zeit. anorg. chem., Bd. 65, 1910, p. 403.

^b Burgess, G. K., *The measurement of high temperatures*, 1912, p. 451.

See also Cowles, A. H., *The solubility of alumina in a bath of fused fluorides*: Met. and Chem. Eng., vol. 11, 1913, p. 177.

^d Wright, J., *Electric furnaces and their industrial applications*, 1908, pp. 186-187.

^e Pascal, P., *Die Elektrometallurgie des Aluminum. Das ternäre System Tonerde-Fluoride-Kryolith*: Ztschr. Electrochem., Bd. 19, 1913, p. 610. Pascal, P. and Jouriaux, M., *Études physico chimiques sur l'électrometallurgie de l'aluminium*: Rev. met., t. 11, 1914, p. 1069; Bull. soc. chim. France, t. 15, 1914, p. 312; Chem. Abs., vol. 7, 1913, p. 2904, vol. 8, 1914, pp. 2529, 3269.

contains 27 per cent Al_2O_3 and melts at $1,270^\circ\text{C}$, whereas Lorenz ^a finds that it contains 33 per cent Al_2O_3 and melts at 940°C . Hence fluorspar is a solvent for alumina.

Pascal finds a ternary eutectic for cryolite, fluorspar, and alumina at the proportions 59.3 per cent cryolite, 23 per cent fluorspar, and 17.7 per cent alumina—a mixture which melts at 868°C .

However, in the published accounts ^b of laboratory experiments for making aluminum, natural cryolite, without the use of CaF_2 or AlF_3 , seems to be the electrolyte used.

Neumann and Olsen mention a mixture of 8 parts cryolite to 1 of NaCl , and also appear to have added some AlF_3 to the electrolyte in some tests. The addition of NaCl to fluorides in the manufacture of aluminum is also mentioned by Minet. ^c A mixture of 40 parts AlF_3 and 60 parts NaCl , another of 20 to 50 parts cryolite and 80 to 50 parts NaCl , and still another of 35 parts AlF , 10 parts NaF , and 55 parts NaCl are suggested.

Plato ^d states that a mixture of 60 parts KCl and 40 parts KF melts at about 610°C , and a mixture of about 86 parts CaCl_2 and 14 parts CaF_2 melts at about 650°C .

That fluorspar was a flux for Al_2O_3 was stated by Mierzinski ^e as far back as 1855, and fluorspar is known to be a good flux for silicates, such as the dirt in most dirty borings doubtless is.

Fedotieff and Iljinsky ^f find that the eutectic mixture for NaF and AlF_3 consists of 36.5 per cent NaF and 63.5 per cent AlF_3 by weight and melts at 685°C . For the manufacture of aluminum they recommend a mixture of the formula $5\text{NaF}.\text{AlF}_3$; this mixture has a lower specific gravity than the eutectic, but has to be run at 900°C in order that the metal may separate well. The use of CaF_2 is not advised, as its specific gravity is even higher than that of aluminum. A mixture consisting of 85 parts CaCl_2 and 15 parts CaF_2 that melts at about 650° to 660°C and has a specific gravity of 2.5, slightly higher than that of molten aluminum, is mentioned by several workers ^g on the electrolytic production of calcium.

^a Lorenz, R., Jabs, A., and Eitel, W., Beiträge zur Theorie der Aluminumdarstellung; Ztschr. anorg. Chem., vol. 83, 1913, p. 39.

^b Richardson, H. K., Some observations on the laboratory production of aluminum: Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 159; Thompson, M. DeKay, The electrolytic reduction of aluminum as a laboratory experiment: Electrochem. and Met. Ind., vol. 7, 1909, p. 19; Tucker, S. A., The preparation of aluminum in the laboratory: Electrochem. and Met. Ind., vol. 7, 1909, p. 315; Neumann, B., and Olsen, H., Production of aluminum as a laboratory experiment: Electrochem. and Met. Ind., vol. 8, 1910, p. 185; Haber, F., and Geipert, R., Versuche über Aluminumdarstellung; Ztschr. Elektrochem. Bd. 8, 1902, p. 1; Borchers, W., Electric smelting and refining, translated by McMillan, W. G., 1904, p. 148.

^c British Patent 10057, July 18, 1887.

^d Plato, W., Erstarrungserscheinungen an anorganischen Salzen und Salzgemischen: Ztschr. phys. Chem. Bd. 58, 1907, pp. 362, 364.

^e Mierzinski, S., Die Fabrikation des Aluminum und der alkaline Metalle, 1855, p. 56.

^f Fedotieff, P. P., and Iljinsky, W., Beiträge zur Elektrometallurgie des Aluminums; Ztschr. anorg. Chem., vol. 80, 1913, p. 113.

^g Ruff, O., and Plata, W., Zur Darstellung des Calciums: Ber. deut. chem. Gesell., Jahrg. 85, 1902, p. 3612. Wöebler, P., Darstellung von metallischen—Calcium für Laboratoriumszwecke; Ztschr. Elektrochem., Bd. 11, 1905, p. 612. Bürgel, C., Über die elektrolytische Gewinnung des Calciums: Ztschr. Elektrochem., Bd. 14, 1907, p. 31.

Arndt and Loewenstein^a show that molten CaCl_2 can dissolve 3 per cent SiO_2 at 820°C ., 5.5 per cent at 900°C ., and 7.5 per cent at 950°C ., and that its specific gravity at 800°C . is 2.05 and at 900°C . is 2.00.

Moldenhauer and Anderson^b give 630°C . as the melting point of the two lowest melting mixtures of CaCl_2 and KCl , one consisting of 85 parts CaCl_2 and 15 parts KCl , and the other, 40 parts CaCl_2 and 60 parts KCl .

It is therefore seen that there are a number of possible mixtures of alkali and alkaline-earth chlorides and fluorides having comparatively low melting points that might serve as a molten cover or flux in melting aluminum chips. Salts of heavy metals are not promising, on account of the reduction of the salts to metal by aluminum, and the salts of few other acids are sufficiently stable at the necessary temperature.

BRIQUETTING BORINGS.

Again it has been suggested that the borings be briquetted, the theory being that in this way the air held by the loose borings is eliminated and the borings put in such shape that they may be readily charged and submerged below the surface of a heel of molten metal.

Such briquets, if made under very heavy pressure, are almost as solid, when cold, as ingot metal. Sperry^c advocates this treatment, and says—

In the treatment of aluminum chips this process is particularly important as this metal, more than any other commercial one, is difficult to treat in such a form. When briquetted, the melting would become a simple operation and the resulting metal now made from aluminum chips is of the poorest quality.

It is claimed^d that borings that gave but 50 per cent recovery when melted loose gave 85 per cent when briquetted, whereas Hirsch^e states that in melting aluminum borings loose borings were melted in 50 minutes per crucible (capacity not stated), with a loss of 13.8 per cent; but briquetted borings lost only 8.1 per cent and melted in 35 minutes.

Two properties of finely divided aluminum must be taken account of in any successful method of melting chips. First, the readiness with which aluminum oxidizes, and second, the difficulty with which tiny globules of molten aluminum coated with a film of oxide or dirt coalesce.

^a Arndt, K. and Loewenstein, W., Über Lösungen von Kalk und Kieselsäure in geschmolzenem Chlorkalium. *Ztschr. Elektrochem.*, Ed. 15, 1909, p. 784.

^b Moldenhauer, W. and Anderson, J., Über die elektrolytische Darstellung von calcium Legierungen und Calcium. *Ztschr. Electrochem.*, Ed. 19, 1913, p. 444.

^c Sperry, E. S., Briquetting metal chips: *Brass World*, vol. 7, 1911, p. 41.

^d Anon., Briquetting metal turnings and borings: *Engineering*, vol. 94, 1912, p. 737; *Jour. Inst. Metals*, vol. 9, 1913, p. 246.

^e Hirsch, E. F., Metall-briketts: *Elektrotech. Ztschr.* vol. 35, 1914, p. 1093.

OXIDATION OF ALUMINUM.

Magnesium powder is the main constituent of many photographic flash-light powders; aluminum powder is also largely used for this purpose and, when suitably heated in the air, burns with explosive violence. Because of its rapid oxidation, finely divided aluminum is used in illuminating bombs and range-finding shells for night use in warfare. The affinity of aluminum for oxygen is so great that aluminum powder, when mixed with the finely divided oxide of the metal it is desired to reduce and the mixture heated in one spot by a suitable primer, reacts with great violence, forming molten aluminum oxide and the metal desired. This is the well-known thermit reaction so much used for the production of difficultly reducible metals, and which produces probably the highest temperatures attainable by man, save those of certain electric furnaces.

Finely divided aluminum, mixed with an oxidizing agent such as ammonium nitrate, whose decomposition products are gaseous, has been suggested as an explosive for miners' use.^a

Aluminum oxide is not reducible to the metal by carbon, even in the electric furnace, only a carbide being formed save in the presence of another metal, as in the Cowles process for the manufacture of aluminum bronze. To reduce the oxide, one must use electrolysis in a fused electrolyte. Aluminum chloride is reducible by metallic sodium or potassium.

Echevarri^b states that in ordinary melting of ingot the metal should not be heated above 725° C. (1,330° F.), as at that temperature aluminum readily oxidizes with the oxygen of the air.

NITRIDATION OF ALUMINUM.

Not only does the oxygen of the air but also the relatively inert nitrogen combine with finely divided, highly heated aluminum. Several workers^c find that if aluminum powder is heated in a current of nitrogen to a temperature of about 700° C. the temperature rapidly rises, even to 1,300° C. in the interior of the mass. Matignon^d states that a temperature of even 2,000° C. is reached, with the formation of aluminum nitride, which coats the tiny globules so that they do not coalesce.

Zappi^e has noted that the more finely divided metallic aluminum is, the greater the protective effect of the oxide coat, as large pieces

^a Sesti, G., Italian Patent 133882, Aug. 7, 1913. Chem. Abs., vol. 7, 1915, p. 1285.

^b Echevarri, J. T. W., Aluminum and some of its metals used: Jour. Inst. Metals, vol. 1, 1909, p. 128.

^c Shokoff, I., Aluminum nitride: Jour. Russ. Phys. Chem. Soc., vol. 40, 1908, p. 457; Sci. Abs., vol. 13, 1910, p. 517; Wolf, J., Zur Darstellung von Aluminiumnitride aus den elementen: Ztschr. anorg. Chem., Bd. 83, 1913, p. 159; Fichter, F., Über Aluminiumnitride: Ztschr. anorg. Chem., Bd. 54, 1907, p. 324; Fichter, F., and Spengel, A., Die Reactionen des Aluminiumnitride: Ztschr. anorg. Chem., Bd. 82, 1913, p. 192.

^d Matignon, C., Synthesis of ammonia by means of aluminum nitride: Jour. Franklin Inst., vol. 178, 1914, p. 794.

^e Zappi, E. V., Action of metals on chloride of carbon: Anales soc. quim. Argentina, vol. 2, 1914, p. 217; Chem. Abs., vol. 9, 1915, p. 2117.

of metallic aluminum react with carbon tetrachloride at 100° C., while aluminum powder does not react at 280° C.

Vickers ^a states that in melting borings under a heel of molten metal considerable nitrogen is absorbed, which will produce minute pinholes in the castings. He states that 0.5 per cent nitrogen will reduce the strength of aluminum alloy one-half, that it is practically impossible to prevent the absorption of nitrogen in melting turnings, and that the only way to remove the nitrogen is to add titanium. Rossi ^b claims that the addition of titanium to aluminum removes both nitrogen and carbon as titanium nitride and cyanonitride.

Sperry ^c states that aluminum absorbs nitrogen while melting. It is also reported ^d that the higher the temperature to which the metal is heated the more nitrogen is taken up. On the other hand, Fichter ^e states that no nitride is formed in melting large masses of aluminum, even if nitrogen be blown into the melt.

In unpublished experiments of H. S. Bennett, of Cornell University, nitrogen was bubbled through 7 pounds of molten pure aluminum held at 960° C. to 1,010° C. for 70 minutes. Physical tests (including the "hot shortness" test ^f) showed no change in properties, although analysis indicated the presence of traces of nitrogen.

Carpenter and Edwards ^g found a nitrogen content ranging from nothing up to 0.0055 per cent in some of the aluminum used by them. The chief chemist of a large aluminum company states that he has never found over 0.001 per cent. One laboratory states that aluminum may contain from 0.0024 to 0.06 per cent. On two samples of a lot of new ingot metal suspected of containing nitrogen, one laboratory found 0.0571 and 0.0376 per cent, whereas a very careful analyst working on duplicate samples of this lot found only 0.0007 and 0.0004 per cent, and in another lot known to have been very strongly overheated he found 0.0004 per cent.

Inasmuch as aluminum nitride does not appear to be soluble in metallic aluminum, it seems probable that if any nitride really exists in ingot refined from borings, it is mechanically included, although Tchijerski ^h claims that aluminum nitride can form a solid solution with iron. However, nitrogen is absorbed in melting borings or in remelting skimmings, when finely divided metal is present and the mass is heated very hot. A nitrogen content that would correspond

^a Vickers, C., How to melt aluminum turnings and borings: Foundry, vol. 41, 1913, p. 119.

^b Rossi, A. J., U. S. Patents 1,056,125, 1,085,488, 1,104,371.

^c Sperry, E. S., Notes: Brass World, vol. 8, 1912, pp. 134, 270.

^d Anon: Some hints on the melting of aluminum: Castings, vol. 11, 1911, p. 2.

^e Fichter, F., Über aluminiumnitride: Ztschr. anorg. Chem., Bd. 54, 1907, p. 324.

^f Norton, A. B., A "hot shortness" testing machine for aluminum alloys: Trans. Am. Inst. Metals, vol. 8, 1914, pp. 124-127.

^g Carpenter, H. C. H., and Edwards, C. A., Eighth report to the Alloys Research Committee: Proc. Inst. Mech. Eng., 1907, p. 57.

^h Tchijerski, N. P., Iron and nitrogen: Rev. Soc. Russ. Met., vol. 1, 1913, p. 127; Science Abs., vol. 18, 1915, p. 256; Rev. met., t. 11, 1915, p. 617.

to 15 per cent AlN has been found in the dross taken off in the remelting of skimmings, a little ZnCl_2 being used as flux.

Richards ^a has called attention to the fact that the dross skimmed off of molten aluminum gives off ammonia in moist air, owing to the formation of aluminum nitride.

On the absorption of nitrogen by mixtures of alumina and carbon at high temperatures are based several processes for the fixation of atmospheric nitrogen, such as those of Serpek, who aims to produce aluminum nitride, and of Peacock, who aims to produce a carbide. Whatever be the exact product or the reaction that takes place in refining borings, it is certain that both the oxygen and nitrogen of the air enter into the formation of the dross. It is also stated ^b that in melting aluminum in graphite crucibles, if the metal is allowed to become very hot and is then stirred so that particles of graphite are scraped off the crucible, some aluminum carbide will be formed. Whether this be true or not, there is some indication that minute traces of some carbide, whether a carbide of aluminum or of some impurity is not known, may be present in most aluminum, as the odor of a freshly fractured surface, such as that of a tensile test bar, often decidedly reminds one of a faint acetylene-like odor ^c and seems to be stronger on the fracture of metal obtained by remelting borings than on that of ordinary ingot. As aluminum carbide (Al_4C_3) with water produces methane instead of acetylene, it is peculiar that so marked an odor should be present if the carbide is one of aluminum itself.

COALESCENCE OF MOLTEN ALUMINUM GLOBULES.

Whether the globules formed when finely divided aluminum is melted are covered with a thin film of oxide, or mixed oxide and nitride, or possibly carbide, or with fine dirt, they do not coalesce readily, but remain as distinct globules, something like drops of water on a dusty table. If a mass of these coated globules could be pictured the mass would show a honeycomb-like formation with the drops of molten metal as the honey and the film of dirt and oxide as the comb. In other words, there is an emulsion of a solid (the film) and a liquid (the metal). If this emulsion is not entirely broken up and the metal freed from the enveloping film, the whole mass of oxide and dirt with the inclosed metal will be skimmed off from what metal has coalesced in the bottom of the crucible. As soon as air strikes this mass of hot porous dross, as it does when the dross is skimmed off, the tiny metallic globules entangled in the dross oxidize at once. The heat of the reaction is so great that a layer of such

^a Richards, J. W., Aluminum nitride: Trans. Am. Electrochem. Soc., vol. 23, 1913, p. 351.

^b Adon., Aluminum melting difficulties: Foundry, vol. 42, 1914, p. 73.

^c See Beckman, J. W., In discussion: Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 177.

dross a few inches thick put on an iron plate a quarter of an inch thick will rapidly burn a hole through the iron.

Fairly large borings free from dirt form comparatively large globules, which can by their own weight break through the enveloping film of oxide, coalesce well, and melt down without much loss. But the smaller borings, that will pass a 20-mesh sieve and may have a thickness of but 0.005 inch or less, form, it will be seen, almost microscopic globules when melted, the weight of which is not sufficient to break through even the very thin film of oxide, to say nothing of adhering dirt.

Skinner and Chubb ^a state that the oxide film obtained in the electrolytic insulation of aluminum wire which is from 0.0001 to 0.0004 inch thick will stand up without rupturing, in small coils, even when the coil is carrying so much current that the wire is molten within this extremely thin shell.

Seligman ^b and Morrison ^c as well as Schoop ^d state that the film of oxide on untreated aluminum wire, which is, of course, infinitely thinner than the film on the electrolytically insulated wire, prevents two wires from welding together without the use of a flux to dissolve the oxide and give true metallic contact.

In "calorizing" iron or steel—that is, coating it with a film of aluminum and aluminum oxide—the piece to be calorized is packed in a mixture of 5 to 50 parts powdered aluminum, 94 to 49 parts aluminum oxide, and 1 part ammonium chloride and then heated to 900° to 950° C.,^e or far above the melting point of the aluminum. The globules of aluminum do not coalesce.

ANALOGOUS PROBLEMS IN COALESCENCE OF OTHER METALS.

MERCURY AND TIN.

The failure of the aluminum to coalesce is similar to the behavior of floured or sickened mercury, globules of which when coated with talc, graphite, grease, or other materials of that nature, coalesce with the greatest difficulty.^f Another case where coalescence of particles of a metal is inhibited by a network of foreign material about them is in fusible tin boiler plugs, where Burgess and Merica ^g find that a little tin oxide may prevent the blowing out of a boiler plug even after the tin is all melted.

^a Skinner, C. E., and Chubb, L. W., The electrolytic insulation of aluminum wire: Trans. Am. Electrochem. Soc., vol. 26, 1914, p. 137.

^b Seligman, R., The welding of aluminum: Jour. Inst. Metals, British, vol. 2, 1909, p. 281.

^c Morrison, W. M., Discussion: Jour. Inst. Metals, British, vol. 1, 1909, p. 150.

^d Schoop, M. V., Autozenous welding of aluminum: Electrochem. Met. Ind., vol. 7, 1909, p. 151.

^e Ruder, W. E., Calorizing metals: Trans. Am. Electrochem. Soc., vol. 27, 1915, p. 254.

^f See Gowland, W., The metallurgy of the nonferrous metals, 1914, p. 305.

^g Burgess, G. K., and Merica, P. D., An investigation of fusible tin boiler plugs: Jour. Wash. Acad. Sci., vol. 5, 1915, p. 461. Trans. Am. Inst. Metals, vol. 9, 1915. Adv. copy 3 pp.

BLUE POWDER.

A closer analogy, however, is that of the difficultly meltable "blue powder" obtained in zinc smelting. Blue powder, according to the general consensus of opinion, consists of tiny globules of zinc which, as they condense from the retort, become coated with a thin film consisting mainly of zinc oxide with perhaps some silica.

The presence of an oxide coating on the particles of blue powder is an advantage for one particular purpose, that of sherardizing, since this coating prevents the coalescence of the zinc dust, which is in this case undesirable. Hence, according to Trood,^a zinc oxide in a zinc dust for sherardizing purposes should not be below 8 per cent.

Roeber^b distinguishes between physical blue powder, or zinc snow, which is finely divided pure zinc free from any coating and according to Hansen^c can be easily remelted, and chemical blue powder, which is finely divided zinc coated with oxide and silica and can not be remelted without great loss.

Ingalls,^d Johnson,^e Lyon and Keeney,^f and West,^g explain the formation of unmeltable blue powder in similar ways.

Peterson^h states, however, that blue powder has the same chemical analysis as spelter, the difference being merely a physical one, and that attempts to melt blue powder in open vessels fail because of oxidation during the heating, before consolidation can take place.

Bleeker,ⁱ on the other hand, states that blue powder contains but 80 to 95 per cent of metallic zinc, the rest being oxide, with traces of other impurities as well.

Ingalls^j gives analyses showing the presence of 7.5 to 10 per cent of zinc oxide, on the average.

By putting blue powder into fused zinc chloride held at a temperature above the melting point of zinc, Bleeker found that some of the zinc coalesced, and that on passing a direct electric current through the molten bath the suspended zinc particles migrated to the cathode and coalesced. The recovery was over 100 per cent, owing to electrolysis of the zinc chloride.

Peterson^k got promising results by this method. He also tried putting blue powder in an iron cylinder with notches, corresponding

^a Trood, S., Sherardizing: Trans. Am. Inst. Metals, vol. 9, 1915. Advance copy, 11 pp.

^b Roeber, E. F., Editorial, Met. and Chem. Eng., vol. 10, 1912, p. 451.

^c Hansen, C. A., In discussion, Trans. Am. Electrochem. Soc., vol. 24, 1913, p. 138.

^d Ingalls, W. R., The electric smelting of zinc ore: Met. and Chem. Eng., vol. 10, 1912, p. 452.

^e Johnson, W. McA., The art of electric zinc smelting: Trans. Am. Electrochem. Soc., vol. 24, 1913, p. 191. Met. and Chem. Eng., vol. 13, 1915, p. 763; U. S. Patent 1,150,271, Aug. 17, 1915.

^f Lyon, D. A. and Keeney, R. M., Possible applications of the electric furnace to western metallurgy: Trans. Am. Electrochem. Soc., vol. 24, 1913, p. 138.

^g West, T., Determination of oxygen in copper and brass: Jour. Inst. Met., vol. 10, 1913, p. 379.

^h Peterson, P. E., The electric zinc furnace: Trans. Am. Electrochem. Soc., vol. 24, 1913, p. 231.

ⁱ Bleeker, W. F., An electrolytic method for the reduction of blue powder: Trans. Am. Electrochem. Soc., vol. 21, 1912, p. 359.

^j Ingalls, W. R., The metallurgy of zinc and cadmium, 1903 ed., pp. 205, 529.

^k Peterson, P. E., Loc. cit.

to tap holes, in the bottom, placing an iron plunger actuated by a screw on top of the powder, heating the whole to 600° to 700° C., and applying pressure with the plunger. In this way he was able to break the film of oxide and make the zinc globules coalesce, getting a recovery of 80 to 85 per cent.

Peterson's furnace is merely a modification of the old Montefiore furnace for the melting of blue powder, described by Ingalls.^a This furnace contained upright boot-shaped retorts into which 40 to 50 pounds of blue powder was charged, a clay piston weighted with an iron bar being put on top of the powder in the leg of the boot to supply pressure to break the oxide film. The metal ran out from the toe of the boot. The yield was 85 per cent to 86 per cent, but the metal occluded a good deal of oxide and was hence of poor quality, so that the use of the furnaces was generally given up in favor of redistilling the blue powder.

Cote and Pierron^b suggest a continuous furnace for the melting of blue powder, in which the powder is fed into a horizontal cylinder within which rotates a solid eccentric cylinder, smooth on one side and bearing helically arranged flanges on the other. The smooth side almost or quite touches the interior of the hollow cylinder and exerts pressure on the mass of blue powder.

The flanges act as a screw conveyor to move the material from the hopper opening at one end to the discharge opening at the other. The blue powder is mixed with a suitable flux and fed into the hollow cylinder, which is kept at 450° to 500° C. (30° to 80° above the melting point of zinc) by various means, among which electrical heating is mentioned, triturated by the inner cylinder and agglomerated into semifluid masses in which the tiny globules have coalesced into much larger ones, and which may therefore be remelted and the oxide released.

It is stated in the patent that from blue powder containing 85 per cent of metallic zinc 80 per cent of the metal, or 68 per cent of the original blue powder, may be recovered, even in a "poor apparatus," and that under good conditions the whole of the metal content may be recovered. As fluxes, sodium, potassium, and calcium chlorides, carnallite, zinc chloride, and sodium and potassium chlorozincates, or mixtures of these, are mentioned. A flux consisting of 60 per cent of NaCl and 40 per cent CaCl_2 , used in the proportion of 15 to 20 per cent of the weight of the blue powder, is recommended.

No information is at hand as to whether or not this furnace has proved commercially successful or as to the maintenance cost.

Richards^c states that one of the difficulties in the electrolytic refining of zinc is the deposition of spongy zinc, which loses 20 to 25 per cent on remelting, though this loss is decreased by using sal ammoniac as a flux.

^a Ingalls, W. R., *The metallurgy of zinc and cadmium*, 1903 ed., p. 527.

^b Cote, E. F., and Pierron, P. R., French Patent 458111, July 29, 1912.

^c Richards, J. W., *The electrolytic deposition of zinc*: Trans. Am. Electrochem. Soc., vol. 25, 1914, p. 281.

Thierry ^a states that attempts made to melt blue powder with sal ammoniac result in a loss of zinc and present numerous difficulties so that the method had not been used in commercial practice.

He further states that in order to make the powder coalesce on melting it is desirable to remove the oxide coating by adding just sufficient hydrochloric acid to dissolve the oxide, without leaving any excess acid to act on the metallic zinc, the proper amount of acid being determined by analysis. The cleaned powder is then compressed to remove the solution, and the blocks melted down out of contact with air. Information as to the commercial operation of this process is lacking.

SUMMARY OF METHODS SUGGESTED.

The methods suggested in the literature for melting aluminum chips and for the analogous problem of melting "blue powder" fall into the following general classes:

1. Feeding the chips back into the aluminum reduction pots and subjecting the melt to electrolysis.

2. The use of a flux, or, more strictly, a molten cover, melting at or below the melting point of aluminum or of the alloy to be remelted, in order to exclude air in ordinary furnaces.

3. The use of a true flux that will dissolve aluminum oxide and dirt.

4. Exclusion of air by stirring the chips into a previously molten "heel" of aluminum in an ordinary furnace.

5. Exclusion of air by the use of a vacuum furnace or a retort furnace, or by utilizing the stored heat in the walls of a previously heated furnace.

6. Briquetting the chips while cold in order to press adjacent chips closely together and thus make coalescence more easy, to reduce the amount of air held by the borings, and to permit easy poking of the borings down under the surface of the molten metal.

7. Subjecting a mass of chips to pressure while melting to promote coalescence, or subjecting it both to slight pressure and to constant stirring, as in the puddling method.

8. Promoting coalescence by stirring a volatile material such as NH_4Cl , ZnCl_2 , or AlCl_3 , which vaporize at 350° , 730° , and 183°C. , respectively, into the mass of globules of metal mixed with oxide and dirt. The gas evolved lifts the particles and stirs them so that some of the tiny globules may come into metallic contact and coalesce. There is also a possibility that the nascent chlorine formed by the dissociation of the substances may react with the oxide film to form the chloride and thus clean the surface of the globule.

9. Cleaning the surface of the chips with chemical solutions before melting.

^a Thierry, C. V., U. S. Patent 1030351, June 25, 1912.

METHODS USED COMMERCIALLY IN MELTING CHIPS.

Seligman^a states that in British practice, as a rule, no flux is used in remelting chips and that the loss is high because of the high temperature needed to free the metal from the dross. He does not consider the use of NH_4Cl or ZnCl_2 to be of much value and states that the use of ZnCl_2 , particularly with pure aluminum, is disadvantageous, as it contaminates the metal with zinc. He has obtained nearly perfect recovery by adding fine scrap and turnings to the reduction pots, but the impurities are likely to upset the bath. He has had good recoveries when using low-melting fluoride-containing fluxes similar to the Schoop flux for welding, even getting ingot from aluminum powder, but such fluxes attack the crucible.

PRACTICE AT AN AMERICAN PLANT.

CRUCIBLE METHOD.

In the practice of one American refining company borings have been melted in various ways, first in coke, pit furnaces, with a small amount of common salt as flux, and later with No. 250 crucibles in either coke or oil-fired pit furnaces. The crucibles were charged with borings and set into the furnace. When the borings became pasty—that is, when the metal melted but had not yet broken through the skin of oxide plus dirt that had formed about each chip—the mass was poked down with a stirrer and more borings added through a long sheet-iron funnel. This was repeated until the crucible was full of molten metal and dross. A little sal ammoniac (commercial ammonium chloride) was added from time to time as the metal was poked and stirred. If the dross seemed free from metallic particles, some of it was taken off with a skimmer during the process of melting, so as to give more room in the crucible. It was considered that the more often the metal was poked down, so as to break the oxide film inclosing the particles, the better would be the results. At the end of the melt the pot was pulled from the fire, and more sal ammoniac was added and stirred and poked well into the dross, a total weight of sal ammoniac equal to about 1 per cent of the weight of borings used being the usual quantity added.

The dross skimmed off in this method was usually somewhat caked together, still contained small globules of molten metal, and was very hot. As soon as it was exposed to the air, violent oxidation, much like the thermit reaction, set in, and the mass glowed with an almost blinding light. If the dross was not spread out thinly, so as to cool rapidly, or else covered thickly with sand, so as to exclude the air, it would get hotter and hotter, evidently from the oxidation and nitridation of the metallic aluminum still con-

^a Seligman, R., in personal letter to G. M. James, March, 1915.

tained in it. When a pile of this dross a few inches thick was put on a $\frac{1}{4}$ -inch iron plate, it would melt a hole through the iron in a short time, and the pile would glow for hours. The dross, when put into water or allowed to stand in moist air, gave off ammonia.

After the dross had been skimmed from the surface of the metal and any adhering below the surface to the walls or bottom of the crucible had been loosened and skimmed off, the metal was cooled by adding some solid ingot poured from a previous melt, as it was so hot that if poured without cooling the ingot would have a poor surface appearance.

It was necessary to get the metal very hot, as otherwise even the larger globules of metal held by the dross would not be fluid enough to break through the enveloping dross and coalesce.

MELTING IN IRON POTS, WITH PUDDLING AND ZINC CHLORIDE FLUX.

This firm has lately changed from crucible melting to iron-pot melting, the new furnaces being similar to those commonly used in aluminum foundries, where it is now more common to melt aluminum alloys in cast-iron pots than in crucibles. The net metal loss in melting ingots for casting in iron pots is not over one-third of 1 per cent, if reasonable care is taken, when the recovery of metal made on remelting the skimmings from the first melting is taken account of.

The furnace used is cylindrical, lined with fire brick, and covered by a heavy iron plate with a hole in it, into which the pot sets, a flange at the edge of the pot holding it suspended in the furnace. The furnace is not sunk in a pit, but stands about $3\frac{1}{2}$ feet high above the floor. The furnace is fired with oil, the flame from the burner entering the combustion chamber below the pot through a hole in the furnace shell and the waste gases being taken off through a port in the shell near the top. The furnace is usually not tilting, and the metal is ladled out, but tilting furnaces using iron pots have recently come into use for melting ingot. In such furnaces the products of combustion do not sweep over the surface of the metal, as they do in a pit furnace, and the metal loss in melting ingot aluminum alloy is less than in crucibles in a coke fire. Resting on the top of the furnace is a sheet-iron cylinder, with a wide door in the front leading into a conical hood, which takes the fumes from the cutting oil and other impurities and the volatile fluxes off to a short sheet-iron stack.

A few borings are put into the pot and heated, with constant stirring, until they become pasty or semifluid. More borings are then added to the mass, which is not allowed to become really molten, but is kept mushy. The borings are puddled all the time, a furnace tender being required for each furnace. The flame, the stirring,

and the feeding of borings are all so regulated that at no time is the metal allowed to become even faintly red.

If the flame is run too high, if the stirring is not sufficient, or if the borings are fed in too fast for proper stirring, oxidation will start in the mass and the temperature will rise rapidly, with consequent increased oxidation and further rise in temperature, till nearly the whole mass will be converted to oxide. Hence the charge is kept small enough—probably between 100 and 150 pounds—so that the furnace tender can keep it all constantly worked over. When no more borings can be added and efficiently stirred in, the pot is covered and the temperature raised somewhat, so as to allow the metal to settle and the dross to rise. Then the bottom and sides of the pot are scraped free from dross and about 2 per cent of fused ZnCl_2 is stirred vigorously into the dross on top. After the zinc chloride has volatilized the dross is taken off with a perforated skimmer. Each skimmerful is allowed to remain in the air only the shortest possible time, the dross being at once dropped into an iron tank partly full of water. Much ammonia is evolved as the nitride-bearing dross reaches the water, and some inflammable gases, probably hydrocarbons, are also produced. With this type of furnace it is possible to stir the metal continuously, which was not the case with crucibles in pit furnaces. The vital points of the process lie in keeping the temperature down while the borings are being added and in constant stirring to promote coalescence.

It is difficult to poke borings down into a crucible or to stir them in a pit fire because of the heat, the necessary length of the stirrer handle, and the choking fumes that arise from the oily borings and from the volatile fluxes used at the end of the heat. In the pot method the heat is not great, the workman is only a couple of feet from the pot and can use his stirrer to better advantage, and the fumes are pretty well taken off.

By the pit-furnace method this firm found it difficult to obtain over 50 per cent recovery, whereas with the pot method the recoveries on the original material, not on the metal content, are given as follows: For 1913, 67.8 per cent, for 1914, 68 per cent, and for the first part of 1915, 69.6 per cent. These figures are on material which includes a certain proportion of centrifuged borings. These borings are sent to the refining plant by an automobile company that uses a water-soluble cutting compound, and states that it uses a centrifugal dryer running at 600 revolutions per minute for drying aluminum chips. The dryer takes a charge of about 175 pounds and three or four minutes whirling reduces the liquid content in the borings to 3 to 5 per cent. No water is added to wash out the cutting compound. After the borings are centrifuged they are stored in sheds until a carload has accumulated, when they are sent to the refiner. The average

recovery on the dried borings is stated by the company to be 85 to 86 per cent, whereas previous to such drying the recovery on the borings was 50 to 60 per cent. There is little dirt in these borings, as the floors about the machines are kept well scrubbed.

Before the centrifuge was used for drying the borings, if borings wet with the cutting compound were placed in the storage bins after a little time fumes would arise that had an odor similar to ammonia or smoked herring, then the borings would corrode rapidly. Now, there is no loss from corroding or overheated borings. Although the recovery is given by the automobile company as 85 to 86 per cent on the borings as shipped from the plant to the refiner, the refiner states that there is usually 4 to 5 per cent of iron borings mixed with the aluminum. The iron is removed as completely as possible by passing the borings over a magnetic separator. Therefore the recovery on the actual aluminum content of the chips is about 90 per cent.

The statement that an odor as of ammonia or smoked herring arose from the damp borings on standing in the air, heated only by the heat of reaction due to oxidation, indicated an interesting fixation of atmospheric nitrogen at low temperatures. Some of the cutting compound used was obtained and both clean millings of pure aluminum and oily No. 12 alloy chips were soaked with it and allowed to stand in the air, and also were heated somewhat by external means, but no odor of ammonia or amines was noted.

MELTING WITH ZnCl_2 - NaCl FLUX IN CRUCIBLES.

Another refining plant, which deals but seldom with aluminum chips, reported that it had sprinkled borings with 2 per cent of a strong ZnCl_2 solution and added 2 per cent of dry common salt, and run the borings down in crucibles in coke fires, getting a recovery of 80 to 82 per cent, but the borings were very clean and nearly free from oil or dirt.

Another refining company which uses a reverberatory furnace is said to get a recovery of 80 per cent. The process is held secret and no details are available as to the exact method of melting, the fluxes used, if any, or as to the quality of borings on which an 80 per cent recovery is made.

REMELTING DROSS.

One aluminum foundry which used merely to remelt the skimmings taken from the regular melting pots and to sell the dross from the remelting at \$20 per ton now washes them in a wet tumbling process, obtaining a concentrate of 800 to 900 pounds of large buttons, free from the adhering dross, from a ton of original dross. The concentrate is remelted promptly—as if left in the air it would oxidize and lose weight—and 400 to 500 pounds of ingot, worth \$60 to \$250, depending on the price of aluminum, is obtained, the saving being far greater than

the cost of treatment. The melting is done in iron pots and sal ammoniac is used as flux. The average recovery is only about 60 per cent of the actual metal content of the concentrate.

In melting down aluminum grindings from the emery wheels used in grinding the rough castings, a recovery of about 6 per cent on the total weight of aluminum plus dirt (the dirt forming at least half the weight) was obtained by this firm, using ZnCl_2 as flux. The grindings as they come from the wheels ordinarily sell for one-half to 1 cent per pound.

This firm made a few experiments on melting borings by heating an iron pot very hot, putting ZnCl_2 in the bottom and immediately charging all the borings the pot would hold, then heating very rapidly, the idea being to melt rapidly and to stir the whole mass by the rising vapor from the ZnCl_2 . Definite figures on this method are not available, but it is stated not to have been very satisfactory.

MELTING WITH SALT AND FLUORSPAR IN CRUCIBLE COKE FURNACE.

At another large refining plant the borings are passed through a magnetic separator and then over an inclined, vibrating, fine-meshed Newago screen, the screen being continually struck by a set of automatically operated small hammers to keep the openings from clogging. The borings are purchased by weight after as much as possible of the iron and dirt is thus removed. This firm has also experimented with various jigs, shakers, and other mechanical devices for separating brass borings from the aluminum borings in the dry way by means of the difference in specific gravities, and with liquation devices for removing pieces of babbitt and white metal, apparently without very satisfactory results.

Passing the chips over a cloth through which air is blown from below, in order to blow out the fine dirt, has also been tried by this firm, but is apparently not so satisfactory as the screen.

The borings are intimately mixed with quite large proportions, apparently between 15 and 30 per cent, of a flux consisting of common salt with a small percentage, probably about 15 per cent, of fluorspar. The mixture of borings and flux is charged into crucibles of about No. 120 size and heated in coke fires. More mixture is added as soon as the first charge can be packed down to make room for it, until the crucible is full. Little stirring, aside from this packing, is done till the end of the heat. The temperature is raised till the flux is fluid enough for the metal globules to separate from it well, when the melt is stirred to promote coalescence of the globules, skimmed, and poured. The flux and dross skimmed off are allowed to cool, crushed, leached with water, and any metallic buttons are recovered by various means of mechanical concentration. The chemist of this firm states that he considers the problem of melting borings as strictly analagous

to welding, for which a flux that will actually dissolve aluminum oxide and dirt, such as the fluxes made up of alkali chlorides and fluorides, are essential. He chose a salt and fluorspar flux for commercial use because of its cheapness. On perfectly clean borings, of good size, recoveries of 95 to 98 per cent are reported by this method, but it is stated that with very oily and dirty borings, where a good deal of fine dirt, such as floor sweepings, foundry sand, or road dust, the latter sometimes intentionally added by unscrupulous junk dealers, adheres to the borings, the recovery falls to 65 per cent.

This firm occasionally uses the same flux, but melts in a reverberatory furnace heated very hot before being charged, as much of the metal as possible being melted by the heat stored in the walls, but ordinarily prefers the crucible method, although the recovery of metal from the reverberatory process is said to be almost if not quite as good as from crucibles.

EXPERIMENTS IN MELTING ALUMINUM CHIPS.

GENERAL METHOD OF MAKING TESTS.

In order to compare various methods of melting on the same lot of chips, two barrels of "No. 12" (92 per cent Al, 8 per cent Cu) chips were obtained. These chips were from the milling machines and drills of a large automobile manufacturing company, and were thought by the firm supplying them to be of such quality that on commercial melting in iron pots, by the puddling method, the recovery would be about 50 to 65 per cent, as that was the recovery usually obtained by a refining company using that method, on the regular run of borings from this automobile firm.

The tests were necessarily on a small scale, a charge of 1 to 2 kilograms being used, in a small crucible heated in a gas-fired furnace.

The metal was poured into small ingot, the relative weight of which to the original weight of borings is recorded as the "primary" yield in the tables of results. The dross, when possible, was skimmed into water, but if the nature of the flux made this procedure dangerous, the dross was allowed to cool, was crushed, and washed in water. The wet dross, with the admixed buttons of metal, was washed in a stream of water on a 20-mesh riddle. The buttons, if large and clean, were weighed without remelting; if small and with adhering dross, they were remelted with the same flux and in the same manner as the original melt. The large, clean buttons, or the ingot recovered from the smaller buttons, form the "secondary" yield. The sum of the primary and secondary yields is the total yield on the basis of original weight, that is, on the weight of borings plus oil and dirt. The total yield on the basis of metal content is obtained by dividing the total yield on the basis of original weight by the metal content of the dirty borings.

KIND OF CHIPS USED.

The chips in barrel A contained about 3 per cent of oil and over 7 per cent of very fine dirt. After the oil had been extracted with gasoline the material was screened; 72 per cent remained on a 20-mesh screen, 18 per cent was between 20 and 80 mesh, and 7 per cent passed the 80-mesh screen. Microscopic examination of the material passing the 80-mesh screen showed only traces of aluminum, the vast bulk of it being merely dirt, mainly siliceous, and appeared to be sweepings from a cement floor. Sticks, paper, peach pits, oily waste, chewing tobacco, and apple cores were present in both barrels. All of the dirt could not be sifted out, even after the oil had been extracted with gasoline. The metal content of barrel A was something less than 90 per cent, but 90 per cent is taken in calculating the total yield on the metallic basis. On material from which the oil had not been extracted, so that the fine borings stuck to the larger ones, sieve tests of borings from barrel A gave the following results:

Over 20 mesh, 80 per cent, which equals 76—per cent of metal plus 4+ per cent of oil and dirt; passing 20 mesh, 20 per cent, which equals 14—per cent of metal plus 6+ per cent of oil and dirt, figured on weight of original material, or the oily borings over 20 mesh contained about 95 per cent of metal, whereas those passing the 20-mesh screen contained about 70 per cent of metal.

When borings from lot A from which the oil had not been extracted were sized on 14 and 40-mesh riddles the results were: 54 per cent over 14 mesh, 42 per cent between 14 and 40 mesh, 4 per cent under 40 mesh.

The chips in barrel B contained about 2 per cent oil, and on chips from which the oil had not been extracted a sieve test showed the following results: 57.5 per cent over 14 mesh, 30.3 per cent between 14 and 40 mesh, 12.2 per cent under 40 mesh.

The material under 40 mesh was practically all dirt, only traces of metallic aluminum being found in it. As about 5 per cent of oil and dirt could be separated from the material over 40 mesh in size, by extraction with gasoline and sifting on an 80-mesh sieve, the total nonmetal content was about 17 per cent. The metal content of barrel B, for purposes of computation, is taken as 85 per cent. The contents of both barrels had been passed through a magnetic separator, but the removal of iron was far from complete.

CONTROL OF TEMPERATURE.

Control of the temperature was attempted, an iron-constantin thermocouple of the rod and tube type being used, but the temperatures were found to vary throughout the charge. The upper part of the charge would become much hotter than the lower part when

any oxidation was taking place in the layer of dross and globules of metal overlying the coalesced mass of metal, as when the furnace cover was removed just before taking out the crucible and pouring.

With fluxes that prevented any visible oxidation, the temperature at the bottom of the melt was often higher than that of the flux on top, because of the poor heat conduction in a heavy layer of molten flux. In the results of experiments where volatile fluxes were used the temperatures given are those of the upper part of the pool of coalesced metal, taken just below the overlying layer of dross, at the time the crucible was taken from the furnace; when other fluxes were used the temperatures given are those of the layer of flux.

MELTING WITH VOLATILE FLUXES.

The results of a series of experiments in which aluminum borings were melted with various volatile fluxes were as follows:

Results of melting borings with volatile fluxes.

NO FLUX USED.

Run No.	Chips from barrel—	Observer.	Weight of chips used.	Flux used, percentage of weight of chips.	Approximate final temperature.	Yield of metal ^a		
						Primary yield, based on weight of chips.	Total yield, based on weight of chips.	Total yield, on basis of metal content of chips.
			Kilogram.		°C.	Per cent.	Per cent.	Per cent.
1.....	A	G	2	.....	910	41	49	54.5

NH₄Cl FLUX USED.

2.....	A	G	2	2	800	62.5	70	b 77
3.....	A	G	2	2	725	45	60.5	67
4.....	A	G	2	5	800	59	65.5	72.5
5.....	A	G	1	2	850	54	60.5	67
6.....	A	G	1	10	850	61	64.5	72
7.....	A	J	1	3	.....	46	49.5	b 55
Average.....							62.5	69.5

ANHYDROUS ZnCl₂ FLUX USED.

8.....	A	G	2	2	875	61	66.5	b 74
9.....	A	G	2	2	760	46	62	69
10.....	A	J	1	3	800	15.5	48.5	b 54
Average.....							59	66

ANHYDROUS AlCl₃ FLUX USED.

11.....	A	G	2	2	850	53.5	65	72
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^a The yields are figured only to the nearest one-half per cent.

^b The borings were not of uniform size in different parts of the barrel, and were difficult to mix thoroughly. Runs 2 and 8 were companion runs on a part that consisted mostly of borings larger than the average, and runs 7 and 10 were companion runs on some borings smaller than the average. The runs were not made in the order given in the table.

In all of these runs borings were packed tightly into the previously hot crucible, poked down as fast as possible, and more borings added with frequent poking and stirring till the whole charge was in. The charge was then stirred from time to time until the end of the melt, when the caked dross that had collected on the sides and bottom of the crucible below the surface of the pool of metal was scraped up, the fluxes were stirred vigorously into the dross, the crucible taken from the furnace, the dross skimmed into water, and the metal poured. If the prices of the three volatile fluxes used be taken into consideration there is not much choice among them on the basis of these results. On a larger scale, the zinc chloride would probably be preferable, as it does not decompose at so low a temperature as the other fluxes, and hence can be stirred into a large mass of dross without much of it volatilizing before it can be stirred in.

MELTING IN ATMOSPHERE OF CHLORINE-CONTAINING GASES.

As the effect of NH_4Cl , ZnCl_2 , and AlCl_3 might be due to the chlorine given off in their decomposition, melting chips in an atmosphere of chlorine or of dry hydrochloric acid gas was tried. The results were as follows:

Results of melting in presence of chlorine and hydrochloric acid gases.

	Run No. 12.	Run No. 13.
Barrel from which chips were taken.....	A	A
Observer.....	G	G
Weight of chips used, kilograms.....	2	2
Gas used.....	Cl_2	HCl
Approximate final temperature, °C.....	810	825
Yield of metal:		
Primary yield, percentage of weight of chips.....	41	32.5
Total yield, percentage of weight of chips.....	56	56
Total yield, percentage of metal content of charge...	62	62

In run 12, Cl_2 gas from a cylinder was run into the top of the crucible, which was open, and the charge was poked and stirred as in runs 1 to 11. In run 13, dry HCl gas was led in through a hole in the crucible cover and the crucible was opened only to poke the charge down and add more borings. Some AlCl_3 was formed in this run.

MELTING WITH CONTINUOUS PUDDLING.

After it was found, late in the investigation, what great stress the refining company that used the iron-pot method with continuous stirring or puddling laid on keeping the temperature down and on the necessity of continuous stirring, that method was tried on

chips from barrel B, as the contents of barrel A had been used up. The results were as follows:

Results of melting with continuous puddling.

	Run No. 14.	Run No. 15.
Barrel from which chips were taken.....	B.	B.
Observer.....	G., J.	J.
Weight of chips used, kilograms.....	1.5	1.5
Flux used.....	ZnCl ₂ .	ZnCl ₂ .
Quantity of flux used, percentage of weight of chips...	2	2
Approximate final temperature, °C.....	800	800
Yield of metal:		
Primary yield, percentage of weight of chips.....	63.5	54
Total yield, percentage of weight of chips.....	66	60
Total yield, percentage of metal content of charge.	78	71

The temperature was not allowed to rise above 700° C. during the addition of borings. As the furnace was not of the iron-pot type, but a crucible was used setting loosely in the furnace, it was difficult for one observer to stir the pasty mass properly and at the same time hold the crucible in place. The gases of combustion also passed over the crucible, which is not the case in the iron-pot furnace, and hence, as the furnace cover had to be left off to permit stirring and holding the crucible, it was more difficult to prevent oxidation than in the regular iron pot. Run 14 was more thoroughly stirred than run 15.

RETORTING.

In one run the conditions of retorting were approximated by packing 1 kilogram of borings into a hot crucible large enough to contain all the borings at the start. The crucible was then tightly covered and heated without any stirring or poking till the end of the melt, when sal ammoniac was added and the mass stirred and skimmed. The results were as follows:

Results of retorting aluminum chips (run No. 16).

Sample used, chips from barrel B.
Observer, G.
Weight of chips used, 1 kilogram.
Flux used, ZnCl ₂ .
Quantity of flux used, on basis of weight of chips, 2 per cent.
Approximate final temperature, 900° C.
Yield of metal:
Primary yield, on basis of weight of chips, 58 per cent.
Total yield, on basis of weight of chips, 64 per cent.
Total yield, on basis of metal content of charge, 71.5 per cent.

MELTING IN A REDUCING ATMOSPHERE.

In order to try the effect of melting aluminum scrap in a strongly reducing atmosphere some tests (Nos. 17 to 21) were made in an

electric crucible lift-out furnace of the Hoskins type and some (Nos. 22 and 23) in one of the indirect-arc type, in both of which furnaces gas analyses showed the atmosphere to be strongly reducing when the furnace was closed. These tests were made before the others herein recorded, on a sample of borings (sample C) that were not so dirty as those from barrels A and B. Sample C contained more oil than samples A and B, however. It was estimated that sample C contained about 5 per cent oil and not over 5 per cent dirt. The dross in runs 17 to 23 was not skimmed into water, and the buttons held in it were oxidized completely, so that the results of the tests, which give only the primary yield, would have been increased somewhat by the secondary yield had the buttons in the dross been recovered. The results follow:

Results of melting borings in a reducing atmosphere.

Run No.	Sam- ple—	Observer.	Weight of chips used.	Flux used.	Amount of flux used, percent- age of weight of chips.	Approx- imate final tempera- ture.	Furnace used.	Primary yield, percent- age of weight of chips.
			<i>Pounds.</i>			<i>° C.</i>		
17.....	C.	G. and L.	12.5	NH ₄ Cl..	2	800	Crucible...	40
18.....	C.	...do....	14	...do....	2	700	...do....	55
19.....	C.	...do....	29	...do....	2	.....	...do....	65.5
20.....	C.	...do....	24.5	...do....	2	.....	...do....	63
21.....	C.	...do....	28	...do....	2	700	...do....	52
22.....	C.	...do....	40	...do....	2	.....	Arc.....	30
23.....	C.	...do....	30	...do....	2	.....	...do....	50

The melts in the crucible furnace were poked and stirred quite a good deal while the oil contained in the borings was smoking off, as the furnace cover could be opened without danger of getting an oxidizing atmosphere, but thereafter no stirring was done till the final addition of NH₄Cl just before taking out the crucible. In the runs in the arc furnace no stirring was done, and the furnace door was opened as little as possible in charging. In the arc furnace the local overheating of the borings as soon as charged seemed to cause enough oxidation, through the air held by the borings, to prevent coalescence, so that a large proportion of dross was formed, which entangled much metal.

HEATING IN ABSENCE OF AIR.

In melting borings from sample A in the gas furnace 1 kilogram of borings was rammed down into the bottom of a hot crucible, and 1 kilogram of molten metal at 800° C., from another crucible, was poured on top of them so as to cover them completely and then the whole was heated. The vapor from the oil in the borings bubbled up through the molten metal that remained on top. No stirring was

done till a thermocouple plunged to the bottom of the crucible showed a temperature of 800°C ., when the whole was stirred and much dross that had collected on the sides and bottom of the crucible was brought to the top. NH_4Cl was then stirred in and the crucible skimmed into water. The results of the test were as follows:

Results of melting borings in absence of air (run No. 24).

Sample used, chips from barrel A.

Observer, G.

Weight of chips used, 1 kilogram.

Flux used, NH_4Cl .

Quantity of flux used, 2 per cent.

Approximate final temperature, 800°C .

Yield of metal:

Primary yield, on basis of weight of chips, 50 per cent.

Total yield, on basis of weight of chips, 61 per cent.

Total yield, on basis of metal content of charge, 68 per cent.

USING A HEEL OF MOLTEN METAL.

Another run was started with a "heel" of 1 kilogram of molten metal in the bottom of the crucible. One kilogram of borings was added a little at a time, an attempt being made to poke them down continually below the surface of the fluid metal—that is, to follow the usual directions for using a heel of metal. This procedure differs from the puddling process in that there is fluid metal in the bottom of the pot, whereas in puddling the whole mass is kept pasty during the addition of borings.

The chips floated on the metal and obstinately refused to stay submerged. The temperature was kept rather low throughout and was, as it proved, not raised sufficiently at the end to give a good separation of metal from dross. The results were as follows:

Results of melting chips with heel of molten metal (run No. 25).

Sample used, chips from barrel A.

Observer, G.

Weight of chips used, 1 kilogram.

Flux used, NH_4Cl .

Quantity of flux used, on basis of weight of chips, 2 per cent.

Approximate final temperature, 700°C .

Yield of metal:

Primary yield, on basis of weight of chips, 39 per cent.

Total yield, on basis of weight of chips, 59.5 per cent.

Total yield, on basis of metal content of charge, 66 per cent.

Other tests on this method and some of the other methods described will be given under the results of sizing and briquetting the chips.

CONCLUSIONS AS TO RESULTS OF TESTS.

In all of the tests described in the preceding pages the fluxes used were volatile and did not form any slag that would tend to protect the metal from oxidation; the dross skimmed off was voluminous, loose, and contained many tiny metallic globules. If any considerable mass of this dross is left in the air it becomes white hot, and then cakes, the loose particles of dirt and oxide being compactly cemented together by oxide formed from the oxidation of the metal in the buttons. No metallic buttons will be found in the mass after cooling in air unless the globule was originally at least the size of a marble and the coating of oxide about it happens to have been so impervious to air that the inside of the globule is protected. Each tiny globule becomes oxidized throughout. The cooled dross is gray in the mass from the presence of dirt, but many tiny globular white specks of aluminum oxide, pseudomorphic after the metal, show where tiny globules of molten metal were contained in the dross when skimmed off.

By showering the hot dross with its entangled globules of metal through the air slowly one can produce an almost continuous sheet of flame. It is impossible to skim the dross into water quickly enough to prevent the burning up of the smallest globules, as exposure for a fraction of a second to the air is sufficient for their oxidation and nitridation. When any considerable amount of dross is skimmed into water there is a very strong odor of ammonia mixed with hydrocarbons. The gas bubbles that arise from the hot dross as it touches the water take fire spontaneously. It appears that there is a good deal of nitrogen and a little carbon chemically combined with the dross.

Although in the last analysis the loss of metal in these methods of melting borings is due to oxidation and nitridation, yet very little of this loss takes place within the furnace in commercial practice in melting in a pit furnace or in an iron-pot furnace, if the pot is covered at the end, or in the gas furnace used in the tests. The dross does not begin to show the thermit-like glowing until it comes in contact with the air. If each and every one of the tiny globules could be made to coalesce in the crucible and to free itself entirely from the dirt and from the small quantity of oxide that actually forms in the furnace, the loss would be very small. The root of the trouble lies in the failure of the tiny, light globules to coalesce.

With this premise it becomes plain why the presence of fine dirt makes the recoveries low, and why, with a given amount of dirt, the smaller the chips are the lower is the recovery. The greater the amount of dirt and the more finely divided the dirt is, the greater is its power to form the honeycomblike coating which envelops the

globules and prevents their uniting. The tinier the chip the greater is the surface of the globule in respect to its weight. The less the weight of the globule the less is the force tending to tear through the enveloping film.

When the borings are even slightly oily, any dust in the borings sticks tightly to them and a surface film of dust tends to be formed before the chip is melted that under the effect of surface tension readily forms a bag about the tiny drop into which the chip changes on fusion.

The small size of some of the chips can hardly be prevented, as they come from the light finishing cut, but the content of dirt can be greatly reduced if care is taken in the collection of the chips.

The tendency toward oxidation of fine chips can be more easily and more readily checked in melting than their reluctance to coalesce can be overcome. It does not seem that, without the use of some slaglike flux to act as a collector of the tiny buttons, such methods as retorting, vacuum-furnace melting, etc., which aim at preventing oxidation, but do not provide for stirring, or other means of promoting coalescence, are likely to offer any advantage in the melting of dirty chips, at least, commensurate with their cost and the difficulties of their operation.

It would therefore appear that if some menstruum or slag were present through which the globules would drop, they might coalesce better, as the dirt would tend to be soaked up by the slag. There would no longer be a honeycomblike coating of solid dirt enveloping the globules, but the globules and the dirt would both be dispersed in a liquid slag. The slag, if lighter than the metal, would also prevent access of air. Hence it seems possible that a molten cover, not necessarily acting as a solvent of dirt and oxide, but merely soaking them up and taking them away from the globules might both promote coalescence and prevent oxidation. It is plain that the most efficient menstruum will be one which is fluid below the melting point of the metal, and which has not only a lower specific gravity than the metal, but also has a low viscosity, so as to allow the globules to sink readily through it.

MELTING WITH MOLTEN COVER.

Suitable molten covers combining these properties with cheapness and with chemical inertness to the metal are, however, not easy to find. Alkali and alkaline-earth chlorides, or mixtures thereof, form the basis of most of the molten covers suggested.

TESTS WITH A COMMERCIAL FLUX.

One such flux is on the market; it has been mentioned, with the makers' directions for using it in melting ingot, on page 17. Although some aluminum founders who have tried this flux reported unfavorably on its use for melting ingot, one even denouncing it as a fraud, some of it was obtained and tried on borings. The flux is a lavender-colored granular material, is soluble in water, tastes like potassium chloride, and melts at about 620° C. The lavender color is due to some organic dye, as it may be extracted by absolute alcohol, in which the material itself is not soluble. The color burns off on ignition, before the melting point is reached. It is perhaps added for psychological effect on the purchaser. Qualitative analysis shows the presence of K, Na, Cl, SO_4 , and a trace of Mg. Quantitative analysis was not made, but it appears that a molecular mixture of KCl and NaCl, plus a little K_2SO_4 would give a mixture of about the same melting point and properties.

In all the following tests on molten covers and other fluxes, the powdered flux was mixed with the borings before charging, and the dross or slag, except where so stated in the tables, was not skimmed directly into water, on account of the explosions that occur in such a case. The dross or slag mixed with dross was skimmed off, allowed to cool somewhat, and thrown into water while still hot in order to disintegrate it. It was then crushed, washed on a 20-mesh sieve, and hand picked. If only a few large clean buttons were obtained, their weight was added to the weight of ingot to give the total yield. If the buttons were small and adhered to particles of slag or dross, they were remelted with the same proportion of the same kind of flux as was used in the original melt and the weight of secondary ingot thus obtained was added to that of the original ingot to give the total yield.

The results of the test with the commercial flux mentioned were as follows:

Results of tests with commercial flux.

Run No.	Chips from barrel—	Observer.	Charge used.	Flux used, percentage of weight of chips.	Approximate final temperature.	Yield of metal.		
						Primary yield, on basis of weight of chips.	Total yield, on basis of weight of chips.	Total yield, on basis of metal content of charge.
			<i>Kg.</i>		<i>° C.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
26.....	A	G	2	5	850	45.0	58.0	64.0
27.....	A	G	2	25	760	48.5	62.0	69.0
28.....	B	J	1	25	900	55.0	62.5	73.5

TESTS WITH DEHYDRATED CARNALLITE.

Dehydrated carnallite, or a mixture in molecular proportions of KCl and $MgCl_2$ has a low melting point and has been suggested as a flux. Tests with this flux gave the following results:

Results of melting borings with flux of dehydrated carnallite.

	Run No. 29.	Run No. 30.
Barrel from which chips were taken.....	A	A
Observer.....	G	G
Weight of chips used, kilograms.....	2	2
Percentage of flux used, on basis of weight of chips....	5	25
Approximate final temperature, °C.....	725	800
Yield of metal:		
Primary yield, percentage of weight of chips.	47	48
Total yield, percentage of weight of chips.	60.5	59
Total yield, percentage of metal content of charge..	67	65.5

DISCUSSION OF RESULTS WITH THE TWO FLUXES.

Neither flux, even when 25 per cent was used, was in sufficient quantity to soak up all the dirt and dross and still become truly fluid. Neither flux rose entirely to the top, but much stuck to the sides and bottom of the crucible.

SPRINKLING WITH ZINC-CHLORIDE SOLUTION AND DRY SALT.

As the use of 2 per cent of a strong solution of $ZnCl_2$ and 2 per cent dry $NaCl$ sprinkled over the borings had been suggested (see p. 30), this was tried. The results of the test were as follows:

Results of melting borings sprinkled with $ZnCl_2$ solution and dry $NaCl$ (run No. 31).

Barrel from which chips were taken, A.

Observer, J.

Weight of chips used, 1.5 kilograms.

Quantity of flux used, 2 per cent of $ZnCl_2$ solution, 2 per cent of dry $NaCl$.

Approximate final temperature, 1000° C.

Yield of metal:

 Primary yield, on basis of weight of chips, 45 per cent.

 Total yield, on basis of weight of chips, 58 per cent.

 Total yield, on basis of metal content of chips, 64 per cent.

The slag was very sticky, almost solid with the dross and dirt soaked up by it, so that it was necessary to heat it very hot to get any separation of metal from it. The slag and dross showed a thermit-like reaction when exposed to air.

TESTS WITH COMMON SALT.

As common salt has been used in commercial practice and is the cheapest alkali chloride, a series of tests was made with varying

proportions of an "agricultural grade" of salt, costing \$2 per ton at the salt works, as flux. The temperatures given are the temperatures in the slag layer at the end of the heat, not in the metal. The results of the tests follow:

Results of melting borings with common salt.

Run No.	Chips from barrel—	Observer.	Charge used.	Flux used, percent- age of weight of chips.	Approximate final temperature.	Yield of metal.		
						Primary yield, on basis of weight of chips.	Total yield, on basis of weight of chips.	Total yield, on basis of metal content of charge.
			<i>Kg.</i>		<i>° C.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
32.....	A	J	1	15	900	45.5	62	69
33.....	A	J	2	20	900	66	69.5	77
34.....	A	J	1	25	900	48.5	61	68
35.....	A	G	1.5	50	900	66	76.5	85
36.....	A	J	1	50	900	59	71	79
37.....	A	J	1	50	900	54.5	61.5	68.5
38.....	A	J	1	50	900	59	65	72
39.....	A	J	1	100	900	47	66	73

With as little as 15 per cent salt the dross was not all soaked up and the mass was dry in places and not wholly pasty and the thermit-like reaction was not wholly stopped. The separation was not good. With 100 per cent of flux the volume of slag was too great to give good separation; 20 to 50 per cent of salt gave pasty slags that were easily skimmed off, gave fair separation, and prevented the thermit-like reaction, although there was not perfect coalescence, as vast numbers of tiny buttons were still held in the slag, passed the 20-mesh sieve, and were lost.

TESTS BY A FOUNDRY WITH SALT AND CALCIUM CHLORIDE FLUX.

Some tests by a foundry, reported to the writers, on NaCl, CaCl₂, and a mixture of the two, as flux, are given below.

SERIES 1, MELTING EMERY GRINDINGS.

Some experimental melts were made in a small crucible, oil-fired furnace; the material used was sawdust from band saws used in cutting off gates, etc., plus emery grindings and emery dust from the grinding wheels. The probable metallic content was between 60 and 70 per cent, the rest being emery dust, floor sweepings, and paraffin used as a lubricant in sawing and grinding. The material would nearly all pass a 20-mesh sieve. The results were as follows:

Charge used.—1½ kilograms.

Run A.—No flux was used. The total recovery of metal was 19 per cent on original weight, all as ingot, no metal being recovered from the dross, as this burnt up on removal.

Run B.—In this run 75 per cent NaCl was used as flux. The total recovery of metal was 47 per cent. Much of this metal was from buttons in the dross, which was not fluid, but was very pasty, almost dry.

Run C.—In this run 30 per cent commercial fused CaCl_2 flux was used. The flux melted and dust was poked constantly into it. The recovery was 43 per cent in good ingot.

Run D.—In this run 75 per cent flux, which was two-thirds commercial fused CaCl_2 , one third NaCl , was used. The total recovery was 38 per cent, mostly in ingot; some metal was recovered as large buttons in the flux cover.

Run E.—This run was made on 60 per cent of old flux, from run D, containing a few aluminum shots from that charge which were not picked out. The recovery was 44 per cent, but most of the metal was buttons from the flux, which was not sufficiently fluid on re-using.

SERIES 2, MELTING DIRTY BORINGS WITH SAL AMMONIAC AND SODIUM CHLORIDE—CALCIUM CHLORIDE FLUXES.

A comparison of sal ammoniac and the NaCl — CaCl_2 mixture as fluxes was made. Exceptionally small, thin, oily, and dirty borings, of unknown metallic content, of very poor quality, were melted in 100-pound charges in an oil-fired iron pot.

Run A.—The borings were constantly poked, and 1 per cent sal ammoniac was used at the end of the melt. The recovery was $12\frac{1}{2}$ per cent.

Run B.—The borings were mixed with 20 per cent of the CaCl_2 — NaCl flux, and were poked occasionally. The recovery was 42 per cent.

SERIES 3, TESTS ON CLEANER BORINGS WITH SAL AMMONIAC AND SODIUM CHLORIDE—CALCIUM CHLORIDE FLUXES.

A similar comparison of the two fluxes was made on commercial borings, of much better quality than in series 2, but containing some oil and dirt. The borings were melted in crucibles in coke fires.

Charges aggregating 316 pounds were melted, with 1 per cent of sal ammoniac as flux. The recovery was 144 pounds, or 44 per cent. On other charges aggregating 346 pounds, with 26 pounds of fused commercial CaCl_2 and 16 pounds NaCl , the recovery was 194 pounds, or 56 per cent.

The flux did not meet with favor by those running the remelting work, largely because of its hygroscopic nature and the consequent difficulty of avoiding dangerous explosions when it is used.

TEST WITH MIXTURE OF CALCIUM CHLORIDE AND SODIUM CHLORIDE.

Chips from lot A were melted with 50 per cent of a flux consisting of 90 per cent commercial fused CaCl_2 , which contained quite a proportion of NaCl , and 10 per cent added NaCl , the mixture becoming fluid at 600°C . The results of the tests were as follows:

Results of melting borings with flux of CaCl_2 and NaCl (run No. 40).

Barrel from which chips were taken, A.

Observer, G.

Weight of chips used, 1.5 kilograms.

Quantity of flux used, 50 per cent (90 parts CaCl_2 , 10 parts NaCl).

Approximate final temperature, 900°C .

Yield of metal:

Primary yield on basis of weight of chips, 61 per cent.

Total yield on basis of weight of chips, 72 per cent.

Total yield on basis of metal content of chips, 80 per cent.

The flux, though fluid at 600°C ., was only just thin enough to skim off properly at 900°C . because of the dirt soaked up by it.

FLUXES CONTAINING FLUORIDES.

In order to get a flux that will not only act as a molten cover to protect the metal from oxidation and a collector to soak up the dirt and permit the globules to coalesce, but will also have a true fluxing or dissolving action both on the dirt and the aluminum oxide, the use of fluorides, as suggested by Schoop,^a was tried.

TESTS WITH VARIOUS FLUORIDE FLUXES.

Various fluoride fluxes were first used, to find out whether better recoveries were obtainable than with the molten covers. Flux No. 1 was as follows: Fluorspar (CaF_2) 16 parts, cryolite ($\text{AlF}_3\text{--NaF}$) 28 parts, aluminum fluoride (AlF_3) 56 parts, this being, according to Wright,^b the composition of the electrolyte used in the production of aluminum. The constituents were fused together, cooled, and the mass pulverized.

Plato^c shows that a mixture of about 86 parts CaCl_2 and 14 parts CaF_2 melts at about 650°C .

Such a mixture (flux No. 2) was made, fused, and pulverized. It was fairly fluid at about 700°C , and the CaF_2 seemed to be all dissolved.

Gleason^d suggests a flux of fluorspar and anhydrous boric acid, in the proportions of three parts of fluorspar to one of boric acid, for another purpose, that of introducing boron into copper by treating such a flux with aluminum and adding it to copper. It was thought that this mixture might give a fluoride flux for the purpose in question, but it was not sufficiently fluid, even at 1100°C , so it was not used.

Jones^e suggests a flux consisting of equal parts LiCl_2 , KCl , and NaF , for use in welding aluminum. Such a flux (No. 3) was made except that KF was used instead of NaF , no NaF being at hand, then fused and pulverized. This flux was extremely fluid at a low red heat.

A flux consisting of 10 parts Na_2CO_3 , 2 parts K_2CO_3 , 2 parts cryolite, and 1 part borax has been suggested^f to be used in the proportion of $1\frac{1}{2}$ pounds per hundredweight of chips. The content of fluorine is so small that this can scarcely be classed as a fluoride flux. Such a flux (No. 4) was made, fused, and pulverized.

Powdered cryolite flux (No. 5) was also tried.

^a Schoop, M. V., U. S. Patent 943,164, Dec. 19, 1909.

^b Wright, J., Electric furnaces and their industrial applications, 1908, pp. 186-187.

^c Plato, W., Erstarrungserscheinungen an anorganischen Salzen und Salzgemischen: Ztschr. phys. Chem. Bd. 58, 1907, p. 362.

^d Gleason, E. D., U. S. Patent 1,076,973.

^e Jones, J. L., Shop problems—fluxing: Metal Ind., vol. 11, 1913, p. 523.

^f Anon., Melting aluminum chips, Castings, vol. 38, 1910, p. 78.

The results of the experiments with the five fluxes named follow:

Results of melting borings with fluxes containing fluorides.

Run No.	Chips from barrel—	Observer.	Charge.	Flux used.	Amount of flux, on basis of weight of chips.	Approximate final temperature.	Yield of metal.		
							Primary yield, based on weight of chips.	Total yield, based on weight of chips.	Total yield, based on metal content of chips.
			Kg.		Per cent.	° C.	Per cent.	Per cent.	Per cent.
41.....	A	G	1	No. 1	25	900	71	72	80
42.....	A	G	1	No. 2	25	900	64	71	79
43.....	A	G	1	No. 3	25	900	65	69.5	78
44.....	A	G	1	No. 4	1.5	900	54	65	72
45.....	A	G	1	No. 4	20	900	50	62	70
46.....	A	J	1	No. 5	15	900	68.5	71	79
47.....	A	G	1	No. 5	25	900	70	71.5	79.5

In runs Nos. 44 and 45, with the soda ash, pearl ash, borax, cryolite flux, which is low in fluorine, the dross showed a thermit-like reaction, whereas the other fluxes gave a pasty mixture of dross and flux which cooled without such reaction. The four fluxes, Nos. 1, 2, 3, and 5, gave consistent results, better than the average results from any other of the fluxes used thus far.

The foundry reporting the results on tests with molten covers also stated that a small laboratory scale test in a crucible in a gas-fired furnace, in which millings free from oil or dirt, being cut without lubricant as a sample for analyses, and rather larger than commercial borings and free from very fine material, with a large proportion of powdered cryolite as flux, had given a recovery of 94½ per cent, although some of the metal was in the form of buttons, as the temperature was not high enough to make the cryolite sufficiently fluid.

TESTS WITH SALT AND FLUORSPAR FLUX.

As the writers learned at this point in the work that a flux of salt and fluorspar was being used commercially, especial attention was directed to that flux, on account of its cheapness, although its melting point is considerably above that of aluminum or its common alloys. As definite information on the proportions of the two ingredients used was not available, experiments were made on various mixtures of the commercial salt and fluorspar that were on hand. The freezing points of mixtures ranging from 90 parts NaCl and 10 parts CaF₂ (about 790° C.) to 75 parts NaCl and 25 parts CaF₂ (about 800° C.) were studied. The mixture of 85 parts NaCl and 15 parts CaF₂, which froze at about 785° C., had the lowest melting point and did not give so viscous a melt as those higher in CaF₂, being quite fluid at 800° C., was chosen as the most suitable composition. One mixture of 85 parts commercial CaCl₂ (containing NaCl) and 15 parts CaF₂

froze at about 660° C. On substituting 5 and 10 per cent of NaCl for similar percentages of CaCl₂, mixtures freezing at about 675° C. and 680° C. were obtained, but all of the CaCl₂ mixtures seemed very viscous at temperatures well above their fusion points and they did not seem to be better fitted for the purpose than the salt and fluorspar mixture, notwithstanding their lower freezing points, and they had the disadvantage of being hygroscopic.

In these runs the flux was intimately mixed with the chips before charging. The borings were rammed down as soon as they got soft and pasty so as to make room for more borings. After the whole charge was in, the crucible was not disturbed or stirred until the temperature of the flux on top of the metal was 900° C., at which temperature it is fluid enough, unless there is too much dirt present in proportion to the amount of flux used, when higher temperatures are needed to make the mass really fluid. Then the crucible was taken from the furnace, stirred gently—too violent stirring will carry globules of metal up into the slag from the metal below—skimmed, and poured. The buttons were recovered from the slag as in the previous experiments.

Results of melting borings with flux consisting of 85 per cent NaCl and 15 per cent CaF₂.

Run No.	Chips from barrel—	Observer.	Charge used.	Quantity of flux, based on weight of chips.	Approximate final temperature.	Yield of metal.		
						Primary yield, based on weight of chips.	Total yield, based on weight of chips.	Total yield, based on metal content of charge.
			Kg.	Per cent.	°C.	Per cent.	Per cent.	Per cent.
48.....	A	J	1	15	900	57.5	64	71
49.....	A	J	2	25	900	68.5	70	78
50.....	A	J	2	25	900	74	75	83.5
51.....	A	J	1	25	900	69	72	80
52.....	A	G	1.5	50	900	70	76	84.5
53.....	A	J	1	50	900	63	68	75.5
54.....	A	J	1	100	900	53	63.5	70.5
55.....	A	J	1.5	20	900	61	65	72

In run 55 the borings and flux were puddled, as in melting with ZnCl₂ in the iron-pot method, and kept pasty by continued stirring till all the charge was in, then at the end the temperature was raised. Apparently nothing is to be gained by so doing, as compared with merely ramming the borings down to make room for the whole charge, and not stirring till the end.

The behavior with only 15 per cent flux or with as much as 100 per cent was analogous to that with similar amounts of salt alone. About 25 to 50 per cent of this flux appears advisable for borings carrying the amount of dirt contained in the lot melted.

SUMMARY OF RESULTS WITH VARIOUS METHODS OF MELTING.

A summary of the results of some of the experimental runs on this consignment of dirty chips, by the chief methods that have been suggested, is shown below:

Results of melting borings by various methods.

No. of run.	Flux or method used.	Number of tests.	Average total recovery, on basis of metal content of charge.	Maximum.
			<i>Per cent.</i>	<i>Per cent.</i>
1	No flux used.....	1	54.5	-----
2 to 7	NH ₄ Cl flux used.....	6	69.5	77
8 to 10	ZnCl ₂ flux used.....	3	66	74
11	AlCl ₃ flux used.....	1	72	-----
14, 15	Puddling, with NH ₄ Cl added at end of melt.....	2	74.5	78
16	Retorting, with NH ₄ Cl added at end of melt.....	1	71.5	-----
26 to 30	Various molten covers, other than NaCl used.....	5	66	73.5
32 to 39	NaCl in proportions of 15 to 100 per cent.....	8	74	85
33 to 38	Common salt in proportions of 20 to 50 per cent used.....	6	75	85
40	NaCl-CaCl ₂ flux used.....	1	80	-----
41 to 47	Various fluoride fluxes other than NaCl-CaF ₂ used.....	7	79.5	80
48 to 55	NaCl-CaF ₂ flux used.....	8	75	84.5
49 to 53, 55	NaCl-CaF ₂ flux in proportions of 20 to 50 per cent used.....	5	80	-----

The best results appear to come from the three following methods: Using NaCl, NaCl plus CaCl₂ in rather large proportion, or from the fluoride-containing fluxes in rather large proportion. Of the fluoride-containing fluxes the cheapest, the NaCl-CaF₂ flux, is apparently as good as those more expensive and seems to give, on an average, sufficiently better results than NaCl without CaF₂ to justify the use of the CaF₂.

In the type of furnace used for the tests, which was not properly adapted to puddling, the use of salt and fluorspar without puddling gave better results than puddling and with much less labor.

This flux was then tested out experimentally under other conditions on briquetted material in a small reverberatory furnace and in an electric furnace.

EXPERIMENTS WITH BRIQUETTED CHIPS.

As is brought out in page 19, compacting the borings into briquets under heavy pressure has been suggested on the theory that such briquets could be more readily plunged under a heel of molten metal than the loose borings, and that the briquetted metal would act much like ingot metal.

However, one refining plant, melting in coke-fired pit furnaces and using sal ammoniac as flux, had some borings briquetted. The briquets were very solid and compact, and could be thrown about without breaking. No quantitative data are available on the results obtained with them; but it was reported that they disintegrated on

melting, and, save for greater ease in charging and possibly greater speed in melting, their use had no advantage over charging loose borings, as the loss was about the same.

A firm selling briquetting machines sent the writers two briquets, stating that they were made from a class of shop fines of No. 12 aluminum containing, unavoidably, a considerable amount of dirt, and that "this class of briquets refused to melt without unreasonable loss." These briquets, which were approximately disks or flat cylinders 3 inches in diameter, 1 inch thick at the edge and $1\frac{1}{2}$ inches thick at the center, were very solid and had apparently been made under extremely high pressure. The briquets were run down with results as follows:

RESULTS OF MELTING BRIQUET NO. 1.

In run No. 56 a heel of metal, consisting of 693 grams of clean No. 12 ingot, was melted in a No. 5 crucible in a gas furnace and raised to a temperature of $800^{\circ}\text{C}.$, when one of the sample briquets, weighing 342 grams, was put in. It sank in the molten metal, a smoky flame, evidently caused by the cutting oil used in machining the castings from which the chips came, being given off. The briquet was poked from time to time with a graphite rod. It disintegrated to some extent and much light dross rose to the surface. Seven minutes after charging the bath was again at a temperature of $800^{\circ}\text{C}.$, and 7 grams of anhydrous zinc chloride was added and stirred into the dross. The dross showed a tendency to glow and heat up, similar to the thermit reaction, indicating that there were still very tiny globules of metal in the dross. The dross was skimmed off into water and the metal poured into ingot. Although the metal had been well stirred, much dross stuck to the bottom and sides of the crucible. After pouring the metal this dross was also skimmed into water. The dross was then washed on a 14-mesh sieve and all buttons over 14 mesh were collected.

In all, 920 grams of ingot were poured and 7 grams of buttons were collected. Deducting the 693 grams of heel metal, there was recovered from the original 342-gram briquet 227 grams of ingot and 7 grams of buttons, or the total recovery was 234 grams. On an assumed basis of 90 per cent metal content and 10 per cent oil and dirt in the briquet, the results are as follows:

Results of melting briquet in heel of molten metal (run No. 56).

	Per cent.
Primary yield, on basis of weight of briquet.....	66.5
Secondary yield, on basis of weight of briquet.....	2.0
Total recovery, on basis of weight of briquet.....	68.5
Total recovery, on assumed basis of 90 per cent metal content.....	76.2

This recovery is not much above the results from loose borings of apparently the same quality as those in the briquet when melted by this method.

RESULTS OF MELTING BRIQUET NO. 2.

Briquet No. 2 was melted with a flux consisting of 85 per cent common salt and 15 per cent fluorspar. As the flux could not be intimately mixed with the briquet, as can be done with loose borings, it was decided to cover the briquet with the flux. In this run (No. 57) it was impossible to cover the briquet in a crucible with so little as 20 to 30 per cent of its weight of this flux, the amount required for loose borings. Accordingly, 200 grams of flux was melted in a No. 5 crucible, and when it had reached a temperature of 800° C. the briquet, weighing 345 grams, was charged. As the flux did not quite cover the briquet, 100 grams more flux was added on top. In 12 minutes the briquet and the added flux had melted and the whole was at 875° C. The flux was then poured off, the metal poured into ingot, and the pasty mass of dirt which had soaked up flux and stuck to the sides of the crucible on pouring was scraped out. The flux and scrapings were disintegrated in water, after being permitted to cool somewhat, and washed on a 14-mesh sieve. In all, 265 grams ingot and 15 grams buttons were recovered, a total of 280 grams. Or the recovery was as follows:

Results of submerging briquet in molten flux (run No. 57).

	Per cent.
Primary yield, on basis of weight of briquet.....	76.8
Secondary yield, on basis of weight of briquet.....	4.2
Total recovery, on basis of weight of briquet.....	81.0
Total recovery, on assumed basis of 90 per cent metal content.....	90.0

CONCLUSIONS AS TO TESTS.

This recovery is better than that obtained on the loose dirty borings of lot A, but the briquets, although they contained some oil and dirt, did not appear to contain quite so much as lot A, hence no conclusions can be drawn from this single small-scale test as to any decrease in melting loss due to briquetting.

Briquetting will increase the ease of handling and probably increase the speed of melting, as the solid briquets transmit heat more rapidly than loose material. Whether it would increase the recovery or not, and whether the cost of briquetting, including labor, power, interest, and upkeep on an expensive press, would be compensated for by increased recovery and decreased labor and fuel cost in melting, can only be determined by large-scale tests on loose and briquetted chips from the same consignment.

In order to utilize the salt-fluorspar flux, it might be worth while to mix 20 to 30 per cent of flux, depending on the amount of dirt in the borings, with dirty borings before briquetting, thus making a briquet with the flux just where it is needed.

REVERBERATORY MELTING.

One firm is refining aluminum borings in a reverberatory furnace and claims 80 per cent recovery. The details are not available as the refiners claim to have a "secret process." Reverberatory melting is also done to a small extent by the firm using the NaCl-CaF_2 flux in crucible melting. This flux is also used when they melt in the reverberatory. Reverberatory melting of aluminum borings is considered by many refiners as out of the question, because of loss by oxidation in melting; also most of the firms melting aluminum ingot consider reverberatory or open-flame melting impossible for the same reason. On the other hand ingot may be successfully melted in an open-flame furnace if a strongly reducing flame is used, and the market alloys put out by the manufacturers of aluminum are usually made in large reverberatory or tilting open-flame, natural gas, or oil furnaces.

In order to determine whether the salt-fluorspar flux, which in crucible melting has consistently given better results than any other flux or method used in the experimental tests, was applicable to reverberatory melting, a small make-shift reverberatory or tilting open-flame gas furnace was built, an old carboy rocker being used for the tilting device, and an old sink for the body of the furnace.

The sink was lined with fire brick and a hearth laid within the fire-brick shell and lined with alundum-magnesite mixture. The hearth proper was about 2 inches deep at the lowest point, $2\frac{1}{2}$ inches wide, 10 inches long on the flat part of the bottom, and sloped up to 5 inches wide by 16 inches long at the top of the hearth. A pouring spout was made at one end and space for a charging hole left above the hearth at the other. An arched fire-brick roof was added, the highest point of which was about 5 inches from the flat bottom of the hearth, or 3 inches above the level of a full molten charge, and 1 inch above the top of the hearth proper at the edges of the hearth on the sides of the furnace. The walls and roof were all 4 inches thick.

City gas, the only kind available, was used to heat the furnace. A home-made burner made from pipe and fittings was placed a few inches in front of the pouring spout. The waste gases passed out the charging hole of the furnace. As the burner was not tightly luted into the mouth of the furnace, but the flame was merely directed into it, air was freely drawn in by injector action. The flame did not heat the furnace very uniformly, the hottest part being about one-third

the way from the front. The rear third of the furnace did not heat up very well, so the furnace was run by tilting it forward a little and utilizing only the front half, the rear being used to preheat the charge, which was poked forward as room was made for it at the front.

It will be seen that it would be difficult to maintain a very strongly reducing flame in such a furnace, so freely open to the air. The temperature varied so throughout the furnace that except on charges melted to a uniform liquid, the temperature of the charge varied with the location in the furnace.

A number of melts of aluminum borings from lot B, containing oil and much fine dirt, with not over 85 per cent metal content, were made. The results of these melts are given below in the order in which they were made:

TESTS IN REVERBERATORY FURNACE.

Run No. 58.—Four pounds of borings were mixed with 1 pound (85 per cent NaCl, 15 per cent CaF_2) of flux and the whole charged into the furnace, which was fairly hot at the start. The run lasted 22 minutes, no attempt being made to keep the flame strongly reducing. The metal was poured before the flux was really fluid, the temperature in the hottest part of the flux being 825°C . Apparently the amount of flux was too small, and the charge a little too large, as the direct flame played on the upper part of the charge. Some thermit-like burning of the charge near the front of furnace was noted.

In this run 1.6 pounds of ingot and 2 pounds of dirty buttons over 20-mesh in size, mixed with balled-up masses of dirt and flux, were recovered. The buttons were remelted with 1 pound of flux, yielding 1.05 pounds ingot, and 0.2 pound of large buttons, the total recovery being 2.85 pounds. The primary yield was 40 per cent, the secondary yield 31 per cent, making a total of 71 per cent, or $83\frac{1}{2}$ per cent on the basis of metal content of charge.

Run No. 59.—The whole charge, consisting of 3.2 pounds borings and 1 pound of NaCl- CaF_2 flux mixed with borings, plus 1 pound flux spread on top after charging, was charged at the start in a hot furnace. The furnace was run 25 minutes and the bulk of the metal poured, then run 15 minutes more to melt the flux, but it was pasty at the end of the run. No thermit reaction was noted. The yield was as follows: Primary yield, 2.4 pounds, 75 per cent; 0.05 pound large buttons, 1.5 per cent; total, 2.45 pounds, 76.5 per cent, or 90 per cent on the basis of metal content of charge.

Run No. 60.—The whole charge, consisting of 3 pounds of borings with 1 pound of flux spread on top, none mixed in with borings, was charged in the furnace, which was warm, but not hot. The run lasted 25 minutes. At times thermit-like burning of the charge was observed. The dross and flux were very dry, not being fluid or even pasty, though the temperature in the hottest part of the furnace was over 900°C .

The recovery was as follows: Primary yield, 1.55 pounds, 52 per cent; 0.2 pound of large buttons, or $6\frac{1}{2}$ per cent; total yield, 1.75 pounds, or $58\frac{1}{2}$ per cent, or 69 per cent on the basis of metal content of charge.

Run No. 61.—Three pounds of borings and 1 pound flux mixed were charged in the hot furnace and $\frac{1}{2}$ pound of flux spread on top. The run lasted 25 minutes; the flux was pasty at the end. No thermit action was observed. The recovery was as follows: Primary, 2.1 pounds, or 70 per cent; large buttons, 0.05 pound, or $1\frac{1}{2}$ per cent; total, 2.15 pounds, or $71\frac{1}{2}$ per cent, or $84\frac{1}{2}$ per cent on the basis of metal content of charge.

Run No. 62.—The whole charge, consisting of 3 pounds of borings and 2 pounds flux, all mixed in, was charged in the hot furnace; ran 20 minutes. The flux was nicely

pasty and a little over 900°C . in the hottest part. No thermit action was noted. The recovery was as follows: Ingot, 2.1 pounds, or 70 per cent; large buttons, 0.05 pound, or 1.5 per cent; total, 2.15 pounds, or $71\frac{1}{2}$ per cent, or 81.5 per cent on the basis of metal content of charge.

Run No. 63.—The whole charge, consisting of 5 pounds of borings and $2\frac{1}{2}$ pounds of flux, all mixed in, was charged in the hot furnace; ran 30 minutes. The charge was too large, as the flame played on top of it. Some thermit action was noted. The mixture of flux and dross was too dry.

The recovery was as follows: Ingot, 2.9 pounds, or 58 per cent; large buttons, 0.15 pound, or 3 per cent; total yield, 3.05 pounds, or 61 per cent, or 71.5 per cent on the basis of metal content of charge.

Run No. 64.—The whole charge, consisting of 3 pounds of borings and 3 pounds of flux, all mixed in, was charged in the hot furnace; ran 20 minutes. The flux was fully fluid at the end of the run.

The recovery was as follows: Ingot, 2.1 pounds, or 70 per cent; large buttons, 0.25 pound, or 8 per cent; total yield, 2.35 pounds, or 78 per cent, or 92 per cent on the basis of metal content of charge.

Run No. 65.—Three pounds of borings, mixed with 1.5 pounds of flux, was charged in the hot furnace and 1 pound of flux spread on top; ran 20 minutes. The flux was nicely pasty.

The recovery was as follows: Primary yield, 2.2 pounds, or 73.5 per cent; large buttons, 0.05 pound, or $1\frac{1}{2}$ per cent; total yield, 2.25 pounds, 75 per cent, or 88 per cent on the basis of metal content of charge.

Run No. 66.—Three pounds of borings were used. No flux was added till the end, then 0.15 pound of sal ammoniac was added and stirred in; the run lasting 17 minutes. The flame used was the same as in previous runs with other fluxes. The melt was only stirred occasionally; very decided glowing or thermit-like action was obtained. The dross was skimmed out on an iron plate and dumped into water at short intervals during skimming.

In this run 1.15 pounds ingot was obtained and many small buttons mixed with adhering dross, which were remelted and yielded 0.1 pound of ingot, 0.05 pound of large buttons; the total yield being 1.3 pounds. The primary yield was 38.5 per cent; the secondary yield, 5 per cent; and the total, 43.5 per cent, or 51 per cent on the basis of metal content of charge.

Run No. 67.—Three pounds of borings were used, and no flux was added until the end of the melt, when 0.15 pound of ZnCl_2 was added and stirred in. The flame was on 12 minutes, the charge being stirred all the time and the borings worked over with a skimmer. The flame was kept as strongly reducing as possible, almost smoky, being much less oxidizing than in previous runs. Not much thermit action was observed until the borings were nearly all melted down, when the whole mass started to heat up almost instantly. The flame was cut off and the mass vigorously stirred for 3 minutes more, then ZnCl_2 was added. The dross was skimmed off as in run 66.

The recovery was as follows: Primary yield, 1.1 pounds, or 37 per cent; large buttons, 0.35 pound, or 11.5 per cent; total yield 1.45 pounds, or $48\frac{1}{2}$ per cent, or 57 per cent on the basis of metal content of charge.

Run No. 68.—The whole charge, consisting of 3 pounds of borings with three-eighth pound NaCl-CaF_2 flux mixed in, and three-eighth pound spread on top was charged in the hot furnace; ran 16 minutes. The flame was not smoky. The flux and dross were too dry.

The recovery was as follows: Ingot, 1.6 pounds, or $53\frac{1}{2}$ per cent; large buttons, 0.25 pound, or $8\frac{1}{2}$ per cent; total, 1.85 pounds, or 62 per cent, or 73 per cent on the basis of metal content of charge.

When the runs are tabulated in the order of the amount of NaCl-CaF_2 flux used, the results may be summarized as follows:

Summary of results in tests with reverberatory furnace.

Run No.	Flux used.	Quantity of flux, based on weight of chips.	Method of adding flux.	Yield of metal—			
				On basis of weight of chips.			Total yield on basis of metal content of charge.
				Primary.	Secondary.	Total.	
		<i>Per cent.</i>		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
66.....	NH_4Cl	5	At end of melt.....	38.5	5	43.5	51
67.....	ZnCl_2	5	do.....	37	11.5	48.5	57
68.....	85 parts NaCl , 15 parts CaF_2	25	Half mixed in charge, half placed on top.	53.5	8.5	62	73
58.....	do.....	b 25	All mixed in charge c.....	40	31	71	83.5
60.....	do.....	33	All placed on top.....	52	6.5	58.5	69
61.....	do.....	50	Two-thirds mixed in charge, one-third placed on top.	70	1.5	71.5	84.5
63.....	do.....	50	All mixed in charge d.....	58	3	61	71.5
59.....	do.....	60	One-half mixed in charge, one-half placed on top.	75	1.5	76.5	90
62.....	do.....	66	All mixed in charge.....	70	1.5	71.5	84.5
65.....	do.....	83	Three-fifths mixed in charge, two-fifths placed on top.	73.5	1.5	75	88
64.....	do.....	100	All mixed in charge.....	70	8	78	92

a Reducing flame, charge stirred constantly.

b 37 per cent including flux used on remelt

c 4 pounds borings, not heated hot enough, 50 per cent of flux used on remelt of secondary yield.

d 5 pounds borings, charge too large, causing flame to strike it.

REMARKS ON RESULTS OF TESTS.

In run 68 evidently not enough flux was used, as the flux plus dross was dry, and the primary yield was low; that is, there was poor separation.

Run 58 showed even poorer separation, as the temperature was not raised high enough. Increasing the proportion of flux on the remelt made up for this somewhat.

Run 60 also shows a poor primary yield, the flux being all on top and not properly protecting the borings.

In run 63 the charge was too large, so that the flame played directly on much of the surface of the charge.

On account of the greater surface in the reverberatory than in the crucible, it is natural that a greater proportion of flux be required.

Runs 59, 61, 62, 64, and 65, with enough flux, of which a sufficient amount was mixed in, averaged a primary yield of 70 per cent and a total yield of 74.5 per cent, based on the weight of chips, or 87.5 per cent on the basis of metal content, as compared with a primary yield of 40 per cent and a total yield of 50 per cent, or 60 per cent on the metallic basis when NH_4Cl or ZnCl_2 was used for flux. That is, the tests, though on too small a scale to be conclusive, indicate that with a suitable flux to coat the globules from the melting of the tiny borings, reverberatory melting may be feasible and give as good results

as crucible melting, whereas without such a flux reverberatory melting is undoubtedly not as good as crucible melting.

These tests, like all the previous ones, have shown better experimental results on the same lot of borings when the $\text{NaCl}-\text{CaF}_2$ flux was used than by any other of the methods advocated.

Robinson ¹ has recently obtained a patent on a process of recovering metals in which he melts salt in a reverberatory furnace, then from time to time adds the aluminum-bearing refuse, mixed with 10 per cent of its weight of cryolite, to dissolve aluminum oxide, preferably operating with constant puddling. As this patent appeared after the experiments herein described were completed, no tests were made of this method.

ELECTRIC MELTING.

A further test of the $\text{NaCl}-\text{CaF}_2$ flux was made on a rather larger scale with a crucible electric furnace of the Hoskins type. Runs 17 to 21 had not indicated any appreciable advantage from melting in the reducing atmosphere of this type of furnace, and the furnace was used merely because it was the most convenient one at hand in the laboratory which would take larger charges than the small gas furnace.

EXPERIMENTS IN MELTING INGOT.

In three runs on ingot, in which a total quantity of 69 pounds of clean No. 12 ingot was remelted in this furnace without flux, the clean ingot poured weighed 68.5 pounds, also 0.5 pound of skimmings and spillings were obtained, of such metal content that at least 0.3 pound of clean metal would have been obtained on remelting them. That is, the actual metal loss was not over the one-third of 1 per cent given by good melting practice with the iron-pot furnace.

EXPERIMENTS IN MELTING BORINGS AND SKIMMINGS.

Three preliminary runs A, B, and C, were made on some odd lots of borings that had accumulated from the previous runs, hereinafter reported, on sizing the borings, and on some skimmings and spillings.

Run A was made on 16.65 pounds of miscellaneous borings, different from but approximately of the same quality as those used in run B, with which 20 per cent by weight of the flux consisting of 85 per cent NaCl and 15 per cent CaF_2 was mixed. The recovery, based on total weight of chips taken, was 11.8 pounds ingot, 0.6 pound buttons, or a primary recovery of 71 per cent and a total recovery of 74.5 per cent.

In run B, on 15 pounds of miscellaneous borings plus 20 per cent of the flux, the primary yield was 11 pounds ingot, or 73.5 per cent, and the total yield 12.2 pounds, or 81.5 per cent, on the basis of total weight of chips.

¹ Robinson, C. S., U. S. Patent 1180435, April 25, 1916.

In run C, on 13.5 pounds skimmings, plus 20 per cent flux, recovery was 11 pounds ingot, or 11.25 pounds in all, or a primary yield of 82 per cent and a total yield of 83.5 per cent. Two runs were then made on chips from lot B with the following results:

Results of melting miscellaneous borings with NH_4Cl and $\text{NaCl}-\text{CaF}_2$ flux.

	Run No. 69.	Run No. 70.
Observers.....	G, L	G, L
Weight of chips taken, pounds.....	15	15
Flux used.....	NH_4Cl	85 parts NaCl . 15 parts CaF_2 .
Percentage of flux used, on basis of weight of chips	2	20
Yield of metal:		
Primary yield, percentage of weight of chips.	53	68.5
Total yield, percentage of weight of chips...	58	71.5
Total yield, percentage of metal content of charge.....	68.5	84

As the crucible was loose in the furnace, not being supported at the sides, puddling was not feasible, so in run 69 the borings were poked and stirred quite constantly as long as oil was smoking off, but the metal was allowed to become more fluid between chargings than was the case in the puddling experiments.

In run 70 no stirring was done till the end, when the temperature was raised well above 900°C ., so that the flux was really fluid.

COMMERCIAL TEST OF SALT AND FLUORSPAR FLUX.

As the iron pot, puddling process and the crucible, salt and fluorspar process appeared to be, from the experimental results and from the reports of the users of the different processes, the two most satisfactory in commercial use, it was suggested to the firm using the puddling process that to test that process against the salt and fluorspar process on the same lot of borings would be of interest. It was pointed out that the higher temperature required in the latter process to make the flux fluid enough to allow a good separation might be too high to permit practical life of the iron pot.

This firm made such a test, using an iron-pot furnace for both methods, and reported as follows:

A lot of borings that had been passed through a magnetic separator was carefully weighed, mixed, and divided into two parts. One part was melted down by puddling, about 2 per cent of zinc chloride being used as final flux; the other part was mixed with 25 per cent of a flux consisting of 85 per cent salt and 15 per cent fluorspar. The cost of flux per 100 pounds of chips was 10.4 cents for zinc chloride and 10.8 cents for the salt and fluorspar flux. The chips contained 13.3 per cent oil and 0.6 per cent free iron left after commercial magnetic separation. The dross from each melt was put in water, concentrated in a tumbling barrel, dried, and assayed, by running down in a small crucible, for its metal content.

Test 1.—1,049 pounds of chips plus 20 pounds of zinc chloride yielded 778 pounds of ingot and 27 pounds of concentrated skimmings containing 74 per cent metal, or 20 pounds, a total of 798 pounds, giving a primary recovery of 74.16 per cent and a total recovery of 76.06 per cent.

Test 2.—508 pounds of chips mixed with 126 pounds of the flux consisting of 85 per cent salt and 15 per cent fluorspar yielded 376 pounds ingot and 22 pounds concentrated skimmings of 62.5 per cent metal content, or 14 pounds, a total of 390 pounds, giving a primary recovery of 74.01 per cent and a total recovery of 76.71 per cent.

Test 1 took $6\frac{1}{2}$ hours and test 2 took 8 hours, or the ingot produced per hour was 119 pounds with the puddling method as compared with 47 pounds by the salt and fluorspar method; that is, the production was cut down 60 per cent. The iron pot used in test 2 was practically ruined at the end of the test, owing to the high temperature necessary to melt the flux. The metal is heated too hot during the melting, thus injuring the quality, in the salt and fluorspar method. The results show that the salt and fluorspar flux can not be used with an iron pot, for the flux has little effect if not pasty or molten, and the temperature necessary for this result is too high for the iron pot. The best place to use such a flux is in melting grindings or very dirty borings. When work slackens somewhat we are going to make a test with a crucible, and will inform you of the results.

No report has yet (June, 1916) been received on the crucible test. From some other comments it seemed possible that this firm had used continuous puddling on test 2 as well as on test 1, although in suggesting the test it was pointed out that continuous stirring was apparently not desirable with the salt and fluorspar flux. An inquiry on this point, and as to whether the borings contained dirt as well as oil was unanswered. From the comment on the apparent applicability of the salt and fluorspar flux to dirty borings, it would seem probable that the borings tested were not dirty.

If the true metal content be taken as the oil-free content, the recovery of 76 to 77 per cent obtained by both methods is equivalent to 88 to 89 per cent on the basis of true metal content, or well above the 68 to 70 per cent recovery, on the basis of original weight of chips, reported by this firm as its average yearly recovery on all borings melted by the puddling process, which would indicate that the borings used were of better quality than the average.

Although the results of this test are unfavorable to the use of salt and fluorspar flux for iron-pot melting, they do not show how puddling in an iron pot and using the salt and fluorspar flux in coke or oil-fired crucible furnaces would compare. The output per furnace was less with the salt and fluorspar flux, but it should be remembered that when salt and fluorspar flux is used the charge does not require continuous stirring, as in the puddling process, and that the output per furnace tender should therefore not be reduced. Of course, the melting of 25 per cent of flux will require more fuel than in a process which does not use a large proportion of flux. Moreover, if the results of the small-scale tests on reverberatory melting would hold on a commercial scale, it would appear that the fuel and labor economies possible from melting in a reverberatory on a larger scale than with crucible or pot furnaces, might perhaps be better gained by using the salt and fluorspar flux, as puddling in a reverberatory would be very difficult.

EFFECT OF SIZING THE BORINGS.

In order to determine whether sifting the borings and melting the larger and the smaller sizes separately would be of advantage, some borings from lot A were sifted on a 20-mesh riddle, 80 per cent remaining on it and 20 per cent passing through it. The results of runs made on these borings were as follows:

Results of melting sized borings from lot A with NH_4Cl flux.

Size of borings.	Run No. 71.	Run No. 72.
	Over 20-mesh.	Under 20-mesh.
Observer.	G	G
Weight of chips used, kilograms.	2	2
Percentage of flux, on basis of weight of borings.	2	2
Yield of metal, on basis of weight of chips:		
Primary yield, per cent.	50.5	8.4
Total yield, per cent.	67.5	18.3

As the total yield on the larger borings, which make up 80 per cent by weight of the unsifted borings, was 67.5 per cent and that on the smaller borings, which make up 20 per cent of that weight, was 18.3 per cent, the total yield on the basis of weight of unsifted chips was $\frac{(67.5 \times 80) + (18.3 \times 20)}{100} = 58$ per cent, which is equivalent to 64.5 per cent of the actual metal content.

A 14-mesh riddle was used in order to get a better separation of larger borings from the smaller ones, and the material passing 14-mesh was sifted on a 40-mesh screen to free it from dirt, the material under 40-mesh being discarded. The two sizes were each melted with the NaCl-CaF_2 flux by heating to 900°C . The following results were obtained:

Results of melting sized borings from lot A with NaCl-CaF_2 and ZnCl_2 .

Run No.	Lot.	Weight of charge.	Size of borings.	Observer.	Flux used.	Quantity of flux used, on basis of weight of chips.	Yield of metal, on basis of weight of chips.	
							Primary.	Total.
73....	A	<i>Kg.</i> 1.25	Over 14-mesh.	J	85 parts NaCl , 15 parts CaF_2 .	<i>Per cent.</i> 15	<i>Per cent.</i> 84	<i>Per cent.</i> 84.5
74....	A	1.25	.....do.....	J	.....do.....	15	87	88
75....	A	1.25	.....do.....	J	.....do.....	25	87	88
76....	A	1.25	.....do.....	J	.....do.....	25	86	86.5
77....	A	1	Between 14 and 40 mesh.	J	.....do.....	25	71	72
78....	A	1	.....do.....	J	.....do.....	25	73.5	74
80....	A	1	.....do.....	J	.....do.....	50	68	68.5
81....	A	1	.....do.....	J	.....do.....	50	70.5	71
82 ^a ..	A	1.5	.....do.....	J	ZnCl_2 .	2	56	61.5

^a Run 82 was made by the puddling process.

In the runs in which the NaCl-CaF_2 flux was used the average total recovery on the material over 14-mesh was 87 per cent and on that between 14 and 40 mesh it was 71.5 per cent. As 54 per cent of the unsifted borings passed the 14-mesh riddle, 42 per cent was between 14 and 40 mesh, and 4 per cent was under 40-mesh and discarded, being practically all dirt. The results may be figured as follows:

$$\frac{(54 \times 87) + (42 \times 71.5)}{100} = 77 \text{ per cent, which is the total recovery on the}$$

basis of the original weight of dirty borings, or 85.5 per cent on the basis of metal content, a recovery that is only slightly better than the average of results on unsifted material and is the same as the maximum. On the very fine material the use of salt and fluorspar flux gave markedly better results than puddling, which suggests that the borings might be sifted and the puddling process used on the cleaner and larger fraction, thus allowing the use of the iron pot for most of the chips, and the smaller and dirtier part melted in crucibles in coke or oil fires with NaCl-CaF_2 flux. This method would reduce the fuel consumption, as more would be required to melt the large amount of NaCl-CaF_2 flux needed were it to be used on all of the borings without sifting them.

Some chips from lot B were also sifted on 14 and 40 mesh riddles, giving 57.5 per cent over 14-mesh, 30.3 per cent between 14 and 40 mesh, and 12.2 per cent under 40-mesh, which was practically all dirt, and discarded. A run (No. 83) was made on the material that was over 14-mesh, in the electric furnace used for runs 69 and 70. The results were as follows:

Result of melting chips from barrel B, over 14-mesh in size, in an electric furnace (run No. 83.)

Observers, G and L.

Weight of chips used, 15 pounds.

Flux used, 85 per cent NaCl and 15 per cent CaF_2 .

Quantity of flux used, based on weight of chips, 20 per cent.

Yield of metal, on basis of weight of chips:

Primary yield, 86.5 per cent.

Total yield, 89 per cent.

This larger scale test on the material over 14-mesh from lot B agreed well with the tests in the small gas furnace (runs 73 to 76) of the material over 14-mesh from lot A. The material from 14 to 40 mesh in size was used in washing tests.

As the large chips are much easier to handle so as to get a high recovery than those under 20-mesh, it would pay to separate them for remelting if some use could be found for the fine material. Where, as in the case cited on page 10, there is a demand for chips for chemical use, this could be done. Possibly the fine material might be used in calorizing, after further comminution, and would offer a cheaper

source of aluminum for that purpose than the aluminum powder now used, provided the copper or zinc in the alloy chips was not detrimental, and provided also that the dirt in the chips would take the place of the aluminum oxide now added to prevent coalescence.

EXPERIMENTS IN WASHING THE CHIPS.

The results in all of the experiments described go to show that clean borings may be melted with comparatively little loss, and that a small content of fine dirt greatly increases the difficulty of making the tiny globules coalesce. When the borings are oily, the dirt sticks tightly to them, so that simply sifting them will not remove the dirt.

Obviously the next experiment to try, then, was to wash the borings so as to free them from oil and then sift out the dirt.

WASHING WITH HOT WATER.

An attempt was made to wash chips from lot A with hot water, in the hope that the oil would be freed from the chips and float to the top. But although the chips in lot A contained about 3 per cent oil, as was determined by ether extraction, not a trace of oil was floated off by the water. Bancroft^a has explained this retention of oil by the fact that aluminum adsorbs oil more readily than it does water. He has found in flotation experiments that if aluminum powder be shaken with kerosene and water, the aluminum goes entirely into the kerosene layer, being floated up by it. In the experiment by the writer the chips, being too heavy to be floated by the small amount of adsorbed oil, held the oil down with them instead of rising with it as in the case of the powder in the presence of much oil.

WASHING WITH A WATER-SOLUBLE CUTTING COMPOUND.

Inasmuch as a high recovery was reported on chips cut with a water-soluble cutting compound and then centrifuged, it was thought possible that oily borings washed with this compound might be cleaned and freed from dirt, so some of the compound was obtained through the courtesy of the makers.

This compound was a stiff white emulsion of oil, soda soap, and water, the water forming over half of the material. On ignition it formed 2 to 2.5 per cent ash, mainly Na_2CO_3 . It was practically neutral in reaction, showing a very faint alkaline reaction with phenolphthalein, due to hydrolysis of the soap. When the compound was stirred into water a very stable milk-white emulsion was formed.

^a Bancroft, W. D., In discussion. Trans. Am. Electrochem. Soc., vol. 23, 1913, p. 294.

Washing chips from lot A with this emulsion did not remove appreciable amounts of oil or dirt, so that the high recovery reported seems due to cleanliness rather than to any specific action of the cutting compound.

WASHING WITH GASOLINE.

Washing with gasoline was then attempted. The borings were washed on a 20-mesh riddle and the fraction over 20-mesh and that under 20-mesh were dried separately. The dry material under 20-mesh was then sifted on an 80-mesh riddle. Only one change of gasoline was used, but it took nearly 5 gallons of gasoline to wash about 60 pounds of borings. The results of washing were as follows: Oil eliminated, 3 per cent; dirt eliminated, 7 per cent; clean borings over 20-mesh, 72 per cent; clean borings under 20-mesh, 18 per cent.

The borings over 20-mesh were quite bright, but there was still some oil not yet washed out and some dirt adhering to them, and on melting down these borings oil still smoked off, though the smoking stopped much sooner than with the original unwashed material. The washed borings under 20-mesh contained a little more oil than those over 20-mesh, and considerably more dirt. As no accurate method of analysis to determine the amount of dirt still retained could be devised, the assumption was made for purposes of computation that the borings after washing were 100 per cent metal.

A heat of washed borings was then run with a mixture of 72 parts of borings over 20-mesh and 18 parts of borings under 20-mesh—that is, a mixture that could be considered as washed but not sifted. The results of this run were as follows:

Results of melting borings washed in gasoline (run No. 83).

Chips from lot A used in test.

Observer, G.

Weight of chips used, 2 kilograms.

Flux used, NH_4Cl .

Quantity of flux used, based on weight of chips, 2 per cent.

Yield of metal, on basis of weight of chips:

Primary yield, 60 per cent.

Total yield, 67 per cent.

As this charge weighed but 90 per cent of what the unwashed borings would weigh, and the washed borings are assumed to be all metal, the total yield given, 67 per cent, is on the basis of metal content, and the total yield on the basis of original weight of chips is 60 per cent.

Samples of the two fractions were then run separately, with results as follows:

Results of melting the fractions separately.

	Run No. 84.	Run No. 85.
Weight of chips used, kilograms.....	.....	.....
Observer.....	G.	G.
Size of borings.....	Over 20-mesh.	Under 20-mesh.
Flux used.....	NH ₄ Cl	NH ₄ Cl
Percentage of flux used on basis of weight of chips.....	2	2
Yield of metal, on basis of weight of chips:		
Primary yield, per cent.....	73.5	26.8
Total yield, per cent.....	81.5	37.3

The average total yield, on the basis of the original weight of unsifted borings, is $\frac{(72 \times 81.5) + (18 \times 37.5)}{100} = 65.5$ per cent, or on the basis of true metal content is 73 per cent. Samples of the two fractions were also run separately, poking each into a heel of 1 kilogram of molten metal, with the following results:

Results of melting borings with heel of molten metal.

Run No.	Chips used.	Charge used.	Size.	Observer.	Flux used.	Quantity of flux used on basis of weight of charge.	Yield of metal on basis of weight of charge.		
							Primary.	Total.	Average.
86....	Chips from lot A, washed with gasoline.	Kg. 1	Over 20-mesh.	G.....	NH ₄ Cl..	Per cent. 2	Per cent. 70	Per ct. 80.5	.....
87.....	do.....	1	Under 20-mesh.	G.....	do.....	2	29.5	41.5	} 40.5
88.....	do.....	1	do.....	G.....	do.....	2	23.5	39.5	

By this method the total yield, on the basis of weight of unsifted borings, is $\frac{(72 \times 80.5) + (18 \times 40.5)}{100} = 65$ per cent, or on the basis of true metal content is 73 per cent.

When runs 84 to 88 are compared with runs 2 to 7 and 24, 25, in which similar melting methods were used on unwashed, unsifted material it appears that there is probably a slight advantage, as regards recovery, in washing and sifting.

Some of the material over 20-mesh washed with gasoline was melted with the NaCl-CaF₂ flux, with the following results.

Results of melting washed borings over 20 mesh in size with NaCl-CaF_2 flux.

	Run No. 89.	Run No. 90.
Observer.....	J.	J.
Size of borings.....	Over 20- mesh.	Under 20- mesh.
Weight of charge used, kilograms.....	1. 25	1. 25
Percentage of flux used, based on weight of bor- ings.....	25	25
Yield of metal, on basis of weight of borings used:		
Primary yield, per cent.....	86. 5	87
Total yield, per cent.....	87. 5	88

The results check with those obtained on melting unwashed borings over 14-mesh with this flux in runs 73 to 76 on chips from lot A and in run 83 on chips from lot B, but are not superior, so that if washing is of advantage its advantage is mainly on the finer borings.

WASHING WITH CAUSTIC-SODA SOLUTION.

No runs were made with this flux on the fraction under 20-mesh, washed in gasoline, as the supply of this fine material was exhausted and gasoline washing seemed to be too expensive a process for commercial use. However, some of the material between 14 and 40 mesh left from the sizing of part of lot B for run 83 was washed in a dilute solution of caustic soda. Caustic soda or caustic potash in dilute solution, is used as a cleaner before polishing aluminum articles. If saponifiable oil or grease is present, it will form a soap that will tend to emulsify paraffin oil. If there is no saponifiable matter in the cutting oil, soap could be added to the NaOH or KOH solution.

Preliminary tests showed that the oil and dirt in chips of lot B were so loosened by the action of a 0.5 per cent solution of NaOH that if the chips were placed in the solution, allowed to remain with constant stirring till slight chemical attack of the NaOH on the aluminum had begun, as shown by a fairly rapid evolution of gas bubbles, a great deal of the dirt was brought to the top by the gas and could readily be floated off with water, which also serves to wash out the caustic solution.

After the chips had been washed, they were freed from water by centrifuging and then drying at 100°C .

The method of washing was rather crude, 1,500 grams of the chips between 14 and 40 mesh being placed in a pan, 5 liters of 0.5 per cent NaOH solution added, and the whole stirred till there was a fairly copious evolution of gas, which required about 10 minutes. Water was then run into the bottom of the pan through a tube and allowed to overflow with constant stirring of the chips until the water ran clear, which took about 10 minutes more.

The chips were then drained and centrifuged. The only centrifuge available was of very small capacity and there was a slight

mechanical loss in transferring the chips. From 1,500 grams of the 14 to 40 mesh chips, 1,412 grams of slightly damp chips were obtained after centrifuging, which, after being dried at 100° C. and 15 grams of dirt sifted out on an 80-mesh screen, weighed 1,362 grams—that is, 9 per cent of the 1,500 grams of the 14 to 40 mesh fraction, or 3 per cent of the unsifted dirty borings, was removed from this fraction by washing. The 1,362 grams were then run down with 20 per cent of the NaCl-CaF₂ flux.

The results of the test were as follows:

Results of melting chips 14 to 40 mesh in size, washed in NaOH solution (run No. 89).

Chips used, from lot A, 14 to 40 mesh, washed in NaOH solution.

Observer, J.

Weight of chips used, 1.33 kilograms.

Flux used, 85 per cent NaCl, 15 per cent CaF₂.

Quantity of flux used, based on weight of charge, 20 per cent.

Yield of metal, on basis of weight of chips:

Primary yield, 72 per cent.

Total yield, 75.5 per cent.

On the basis of the 1,500 grams originally taken, the total recovery was 68.5 per cent, which is slightly less than the yield of 71.5 per cent obtained in runs 77 to 81, which were made on the unwashed 14 to 40 mesh fraction from lot A, but it must be remembered that the chips in lot A were not so dirty as those in lot B.

As the recovery on the unwashed fraction over 14 mesh in size used in run 83 was 89 per cent, the total recovery, calculated on the basis of original weight of unsifted material, is

$$\frac{(57.5 \times 89) + (30.3 \times 68.5)}{100} = 72 \text{ per cent,}$$

or, on the basis of true metal content, 85 per cent.

Two 1,500-gram samples of the unsifted borings from lot B were then washed with NaOH solution, centrifuged, and dried, one yielding 1,326 grams and the other 1,316 grams. These samples were run down with 20 per cent of NaCl-CaF₂ flux, with results as follows:

Results of melting unsifted borings from lot B, washed in NaOH solution.

	Run No. 90.	Run No. 91.
Observer.....	J	J
Weight of borings used, kilograms.....	1.5	1.5
Flux used.....	80 parts NaCl 15 parts CaF ₂	80 parts NaCl 15 parts CaF ₂
Quantity of flux, on basis of weight of chips, per cent.....	20	20
Yield of metal:		
Primary yield, percentage of weight of chips.....	71	70
Total yield, percentage of weight of chips.....	74.5	75
Total yield, percentage of metal content of chips.....	87.5	88.5

These results show enough improvement over those on unwashed chips from lot B to make it seem possible that washing dirty borings with dilute NaOH solution might be worth while. One method that suggests itself for trial on dirty borings is to use a concentrating table of the Willley type, fed not with water but with dilute NaOH solution, or with a solution of both NaOH and soap, the solution to be run into a settler and pumped back into the system, followed by washing with water and centrifuging.

From the comparative readiness with which dirt was freed from the chips in the experiments it would seem that such treatment would be worth a commercial test. As most refining plants and many nonferrous foundries are now equipped with concentrating tables for use on brass-foundry wastes, the only unusual piece of apparatus required would be the centrifuge.

Borings thus cleaned and dried would probably be more readily separated from free iron on being passed over the magnetic separator than oily borings. Were a centrifuge installed, very oily borings, such as contain 10 per cent or more of oil, might be run through the centrifuge before washing, which would leave less work for the cleaning solution to do, and the cost of the operation would probably be compensated for by the value of the oil recovered.

MISCELLANEOUS EXPERIMENTS IN ELECTRIC FURNACES.

After the experiments above cited had been completed, another indirect arc furnace was constructed for other purposes, and the question arose whether or not the furnace would be applicable to melting aluminum chips.

Another lot of No. 12 alloy chips, designated as lot D, was obtained from a large refining company, which stated that it had made a 77 per cent recovery, on the basis of the weight of the chips, from these chips by the puddling process.

On chips that were sized without extracting the oil, the recoveries were as follows: Chips over 14 mesh in size, 62 per cent; between 14 and 40 mesh, 30 per cent; and under 40 mesh, 8 per cent. By extraction with ether, 5 per cent of oil was obtained; and by sifting the oil-free borings on a 40-mesh sieve, and carefully floating off the dirt from the small amount of aluminum that passed the 40-mesh sieve, 7 per cent of dirt was obtained. Hence the chips contained at least 12 per cent of nonmetallic material, and the metal content was not over 88 per cent. This means that in commercial practice the puddling process gave a recovery of 87.5 per cent of the metallic content.

EXPERIMENTS WITH INDIRECT ARC FURNACE.

The indirect arc furnace resembled in form a horizontal cylinder. The melting chamber was 15 inches in diameter and about 15 inches long. Graphite electrodes 2 inches in diameter were passed horizontally into the center of the chamber, and the arc was formed between them. The furnace lining forming the melting chamber was of fire brick, coated with asbestos cement, and this layer was coated with alundum magnesite mixture.

MELTING WITH ALUNDUM-MAGNESITE LINING.

Run No. 92.—Twenty-five pounds of chips, mixed with 10 pounds of flux, consisting of 85 parts NaCl and 15 parts CaF_2 , was charged into the cold furnace. The charge came within about 2 inches of the arc. After 42 minutes heating in which 20 kilowatt-hours were used, a pool of metal had collected in the bottom, and the temperature was 900°C . The flux was not fluid and still held many buttons of metal, and a few unmelted chips remained in the bottom of the furnace. The yield of ingot was 6.25 pounds, or a primary yield of 25 per cent on the basis of original weight of chips charged. The flux was scraped out and on being crushed and washed yielded 8.25 pounds of buttons, or 35 per cent, which, with the 25 per cent previously obtained, made a total recovery of 60 per cent, on the basis of original weight of chips.

It was evident that the charge as a whole was not hot enough, and that it would have been better not to charge so many chips at once. The magnesite-alundum lining was badly attacked and began to crumble off, and as this was believed to be due to the effect of the fluorspar, it was decided to try common salt in the next heat.

Run No. 93.—Ten pounds of chips mixed with 5 pounds NaCl was charged into the cold furnace and the current turned on, 17 kilowatt-hours being used in 29 minutes, then 10 pounds of chips mixed with 5 pounds of NaCl was added. Heating was continued 25 minutes more, using 13 kilowatt-hours, or the total power input was 30 kilowatt-hours. The temperature was over $1,000^\circ\text{C}$, but the mass of NaCl and dross was only pasty. From the 20 pounds of chips charged, 7.5 pounds ingot and 5 pounds of buttons were obtained, or a primary yield of 37.5 per cent and a total yield of 62.5 per cent, on the basis of original weight of chips. The lining continued to crumble.

Run No. 94.—The furnace was preheated by the use of 15 kilowatt-hours and then 15 pounds of chips, plus 15 pounds of flux, consisting of 85 parts NaCl and 15 parts of CaF_2 , was charged. Ten pounds of the flux was mixed with the chips, and 5 pounds placed on top of the charge. After 27 minutes, in which 15 kilowatt-hours more

was used, the charge was at a temperature of 900°C . The bulk of the flux was fluid, but it contained some matted masses of flux and dross that were only pasty. Seven and one-half pounds of ingot and some flux were poured. The flux that poured out with the metal was replaced in the furnace and heated 20 minutes, in which 10 kilowatt-hours were used. Two and nine-tenths pounds ingot was obtained on the second pour. The flux was all fluid at this time. Besides the total of 10.4 pounds of ingot, 0.9 pound of buttons was recovered from the slag, giving a primary or ingot yield of 69.5 per cent and a total yield of 75 per cent on the basis of the weight of chips charged. The lining was still crumbling badly, and after the furnace had cooled all loose pieces were taken out. By this time most of the alundum magnesite layer of the lining had come off. It appeared that with a lining not attacked by the flux and with sufficient flux fair recoveries might be made.

Run No. 95.—In order to determine whether less flux than was used in the previous run would serve, run 95 was made, after the furnace had been preheated for 15 kilowatt-hours, by charging 18 pounds of borings mixed with 8 pounds of the flux (85 parts NaCl , 15 parts CaF_2) and placing 3 pounds of flux on top of the charge. After 44 minutes, in which 22.5 kilowatt-hours was used, there was a pool of metal in the furnace, and 10.2 pounds of ingot was poured, but the flux was not fluid. The heat was continued for 18 minutes, 7.5 kilowatt-hours being used, and 1.4 pounds more ingot was poured. The flux was still only pasty. Five-tenths pound of buttons was recovered from the slag, giving a combined primary or ingot yield of 64.5 per cent and a total yield of 67.5 per cent on the basis of chips charged.

The furnace was then cleaned, and a run made on a charge of 37 pounds of ingot. Starting with a cold furnace, it took 52 minutes' time and a power input of 30 kilowatt-hours to heat the charge to 735°C . Twenty-five pounds more of ingot was then added, and 10 more kilowatt-hours used in 13 minutes. The charge was then at 870°C ., or hotter than is needed for pouring aluminum castings. Of course, after the furnace is once hot, the power needed to melt a given charge will be less than when the furnace must be heated also. Moreover, a furnace of commercial size will be much more efficient than a small laboratory furnace. Nevertheless, the power required for the electric melting of aluminum, even under the most favorable conditions, will be high. In this heat, which was started with a cold furnace, a total power input of 40 kilowatt-hours was required to heat 62 pounds of aluminum to 870°C ., and 10 kilowatt-hours to melt 25 pounds and raise it to 870°C ., and also to raise the first 37 pounds from 735° to 870°C . This furnace, started cold, has melted 125

pounds of red brass ingot and heated it to $1,150^{\circ}\text{C}$. with 40 kilowatt-hours, and after the furnace was hot 19 kilowatt-hours has melted and heated to $1,200^{\circ}\text{C}$. 130 pounds of red brass ingot.

That is, it took about twice as much power per pound to heat the aluminum to its pouring temperature as it did to heat red brass to its pouring temperature. This is in accord with theory. Richards ^a has calculated that theoretically about 278 heat units are required to heat aluminum to about 710°C ., whereas only about 130 heat units are required to heat brass or bronze to about $1,050^{\circ}\text{C}$. The difference is due to the extremely high heat of fusion of aluminum, the relative heats of fusion being as follows: Aluminum, 100; copper, 43; zinc, 23; tin, 14; and lead, 4. This high heat of fusion overbalances the higher temperatures needed for brass and bronze.

Only in exceptional circumstances can electric furnaces compete with fuel-fired furnaces in melting brass, unless the alloy is one on which the use of an electric furnace can reduce the zinc loss, because of the high cost of electric power compared to fuel. Therefore it is evident that there is little hope of the electric furnace being able to compete with the oil-fired, iron-pot furnace in melting ingot aluminum, as ingot can be melted in pot furnaces with a loss of only one-third of 1 per cent, and there is no such margin for metal saving as in the case of brasses high in zinc.

When a large proportion of flux is to be melted, as in the fluxing method for aluminum chips, still more power will be required than in the melting of aluminum ingot. In the experimental furnace, and in most tilting electric furnaces, it is inconvenient or impossible to press the charge of chips and flux down into a compact mass, as is done in crucible melting. It is well known ^b that at temperatures below a red heat, a porous mass with inclosed air spaces is a good heat insulator and a poor heat conductor, so that notwithstanding the high heat conductivity of aluminum a mass of chips does not conduct heat very rapidly. Thus, if the layer of loose chips on the furnace hearth is thick, the top part of the layer, being nearest the arc, may be seriously overheated before the bottom part is hot enough to melt. From the salt fumes coming from the arc furnace when pouring, it appears probable that much salt is volatilized from the top of the layer, and that the chips on the top of the bath fail to coalesce and are so hot that they oxidize as soon as the furnace is opened to charge or to pour, and air enters. Hence much more flux is necessary than where the borings can be jammed down into a crucible, although in crucible melting with flux the constant stirring necessary in the puddling process is not required.

^a Richards, J. W., Electric power required to melt metals: Trans. Am. Brass Founders' Assn., vol. 4, 1910, p. 93.

^b Ray, W. T., and Kreisinger, H., The flow of heat through furnace walls: Bull. 8, Bureau of Mines, 1911, 32 pp.

In an arc furnace the main source of heat is the arc itself, although some heat is of course reflected from the roof. As the arc is much hotter and much smaller than a flame, there is more danger of local overheating at the surface of the charge in an arc furnace than in a reverberatory furnace, where a sheet of flame covers the whole charge. An uncompacted mass of chips and flux, even at 900°C ., is so viscous that rocking the arc furnace back and forth fails to stir the mass enough to mix it and prevent local overheating.

Hence, although there is a possibility that in a suitably lined electric furnace, where the lining is not attacked by the flux (linings of magnesite brick or mixtures of graphite and fire clay might perhaps serve) aluminum borings could be melted on a larger scale than in iron pots or crucibles, the reduction in labor cost would probably be more than offset by the higher cost for power as compared with the cost for fuel in ordinary types of furnaces.

EXPERIMENT WITH GRAPHITE CRUCIBLE LINING.

Another run was made to determine whether the indirect arc furnace would give satisfactory results with a better lining, as regards losses, without using so much flux as in run 94. It was thought that the lining that had crumbled off had acted like so much dirt in the chips and required excessive amounts of flux.

As neither magnesite brick nor graphite and fire clay mixture was at hand, a No. 60 crucible was used as a lining for the furnace. A hole for the passage of the electrode was cut in the bottom of the crucible, and a hole for the charging door and pouring spout was cut in the side. The crucible was placed horizontally inside the furnace and fire clay was packed between the crucible and the former furnace lining and the hearth at the mouth end of the crucible, the packing being completed with a mixture of ground crucibles and enough fire clay for a bond. This reduced the capacity of the furnace very greatly.

Run No. 96.—After the furnace had been preheated with a power consumption of 12 kilowatt-hours, about two-thirds of a charge of 8 pounds of chips mixed with 2.4 pounds of flux consisting of 85 parts NaCl and 15 parts CaF_2 was added. After 15 minutes, when 8 more kilowatt-hours had been used, the other third was charged, and after heating 5 minutes longer, 3 kilowatt-hours being used, the charge was at 975°C . The flux was only pasty and some thermit-like action was noted on top of the charge. Three and seventy-five hundredths pounds ingot and 1.25 pounds buttons were obtained, or a primary yield of 47 per cent, and a total yield of 62.5 per cent, on the basis of chips charged. As the crucible used as lining was not attacked and the result of this run was poor, the poor results of previous runs were evidently not mainly due to the crumbling of the lining.

Although run 94 indicated that with a sufficient amount of flux, electric melting in an indirect arc furnace might be possible, it seemed very unlikely that it would be commercially profitable and experiments with the indirect arc furnace were discontinued.

EXPERIMENTS WITH CRUCIBLE, RESISTOR FURNACE.

As lot D was from chips on which the commercial recovery was known to be 77 per cent on the weight of the chips, it was decided to make a few crucible melts to compare the experimental results with the commercial ones.

For these melts a No. 10 crucible was embedded in the granular graphite resistor of an electric resistor furnace, the crucible being taken out for pouring.

Run No. 97.—The crucible was first heated to dull redness, then small amounts of borings were added from time to time and puddled, care being taken not to let the temperature rise appreciably above the melting point. It took 10 minutes thus to work in 3 pounds of borings. Then the crucible was covered and heated 3 minutes more, when 2 per cent of fused ZnCl_2 was stirred in, the dross skimmed into water, and the metal poured. The dross showed a little thermit-like action. Two and twentth-five hundredths pounds ingot and 0.5 pound buttons was obtained, or a primary yield of 75 per cent and a total yield of 77 per cent, on the basis of the weight of the chips—that is, the same recovery was made as was found commercially.

Run No. 98.—Borax, which has been suggested as a flux for aluminum chips, not having been previously tried, 3 pounds of chips and 0.75 pound of pulverized crystalline borax, equivalent to about 0.4 pound borax glass, were mixed together and most of the mixture was charged into the cold crucible. The furnace was then heated and after 16 minutes the rest of the charge was added and the whole poked continually as it melted down, to approximate conditions in the puddling process. After 7 minutes more the charge was heated to more than $1,000^\circ \text{C}$. but the borax flux was only pasty, and mostly at the bottom of the crucible. The ingot recovery was 2.1 pounds and there was 0.20 pound of buttons, giving a primary yield of 70 per cent and a total yield of 76.5 per cent on the basis of chips charged. There was no thermit-like action.

Run No. 99.—As it seemed possible that the use of a larger amount of borax, with the addition of some fluorspar, might give a more fluid flux, the next run was made as follows: Three pounds of chips mixed with 1.2 pounds of pulverized crystalline borax and 0.1 pound fluorspar were charged into the hot crucible. In 16 minutes the temperature was over $1,000^\circ \text{C}$., but the aluminum was all on top and the flux all on the bottom. Only 1.3 pounds ingot, or 43 per cent primary recovery, was obtained. The mass of flux in the bottom of the crucible was full of exceedingly minute globules of

metal, which were not recovered. Borax is evidently too heavy to serve as a good flux.

Run No. 100.—Five pounds of chips was mixed with 1.5 pounds of the flux, consisting of 85 parts NaCl and 15 parts CaF_2 , and as much as possible of the mixture was packed into the cold crucible. After 20 minutes heating the rest was added, and after a total of 49 minutes the charge was at 950°C . The flux was quite fluid. Three and seventy-five one-hundredths pounds ingot and 0.10 pound of buttons were obtained, or a primary yield of 75 per cent and a total yield of 77 per cent on the basis of weight of chips taken.

Run No. 101.—Five pounds of chips was washed 10 minutes with 5 liters of 0.5 per cent NaOH solution, which removed much dirt, the NaOH was washed out, and the chips were stored under water 4 hours. They were then drained of water, mixed with 1.5 pounds of the flux, consisting of 85 parts NaCl and 15 parts CaF_2 , and most of the damp mixture charged into the warm crucible. No oil smoked off, showing that it had been removed by the washing. After 15 minutes the rest of the charge was added, and after 15 minutes more the temperature was 975°C . The slag was fluid. Three and sixty-five one-hundredths pounds of ingot and 0.15 pound of buttons were obtained, or a primary yield of 73 per cent and a total yield of 76 per cent on the basis of weight of chips. There was a slight mechanical loss in washing and transferring the moist chips.

CONCLUSIONS FROM RESULTS OF TESTS.

The recoveries with the puddling method and the salt-fluorspar flux method, the latter on both dirty and washed chips, were practically identical and the same as the commercial recovery on these chips—that is, about 77 per cent on the weight of the chips and 87.5 per cent on the metallic content. As the use of salt-fluorspar flux had given better results on previous lots of chips in a gas furnace than the puddling method, it seems likely that the previous poorer results of the puddling method may have been largely due to the fact that the products of combustion in the gas furnace were continually sweeping over the metal as it was poked in. In run 97 there were no products of combustion, and the conditions were very like those in the iron-pot furnace.

It appears that, as puddling can not be done efficiently in a pit furnace, the use of salt-fluorspar flux is the most promising method of melting chips in pit furnaces. The temperatures required in the flux method are too high for the iron-pot furnace, and in that furnace the puddling method is preferable. In reverberatory melting the flux method is probably the better.

The choice of the three methods—puddling in the iron-pot furnace, use of the flux in pit or tilting crucible furnaces, or of the flux in a reverberatory furnace—for commercial refining can not be decided by

laboratory tests. Costs of fuel, flux, crucibles or iron pots, furnace repair, and labor, the output in regard to floor space and furnace cost, the yield of ingot, the quality of ingot, the ease of recovering buttons from slag or dross, and other factors must all be taken into account in making a choice. It seems likely that for very clean chips the iron-pot puddling process would be more economical, whereas for very dirty chips the flux methods, whether in crucibles or in a reverberatory furnace, would apparently have a slight advantage.

QUALITY OF INGOT FROM ALUMINUM CHIPS.

Ingot made from dirty aluminum borings or chips is necessarily somewhat less pure and less desirable than virgin metal. One would hesitate to use all boring ingot in important castings. However, in small castings, such as are molded on the bench, if they do not have to stand a pressure test, 10 per cent of good boring ingot can usually be added to 90 per cent of new metal and back gates without increase in the proportion of defective castings and without detriment to the quality of the castings. In the case of large castings of complicated design, it is a moot question among aluminum founders whether or not the use of boring ingot increases the amount of castings defective through cracking in the mold. In some cases which have come to the attention of the writers, boring ingot has given very low "hot shortness" tests, which would indicate a liability toward cracking in the mold. On the other hand, some foundry men have claimed that certain boring ingot, used in quantities even up to 30 per cent of the weight of the charge, markedly decreases the loss from cracking, although other ingot of practically the same composition markedly increases it. The matter is a difficult one to settle, as so many factors, such as the relative hardness or softness of the cores, the ramming of the mold, the temper of the sand, the design of the casting, the gating, and the temperature at which the metal is poured, may all have as much or more effect on the tendency to crack as has the composition of the metal. In fact, the analysis of the metal gives no real criterion as to its tendency to crack.

However, it is true that some metal does crack worse than other metal of the same composition. Some unpublished results of work by H. Goldberg have indicated that metal melted under conditions where waste gases from a strongly oxidizing flame may reach it is more likely to crack than would the same metal if melted under reducing conditions.

Although boring ingot does not command the price of new metal, a boring ingot not too high in impurities finds a ready market at a price not much below that of new metal, and this is the best indication that there are plenty of castings in which boring ingot may be satisfactorily used.

On the other hand, there has been some boring ingot on the market, evidently made from a miscellaneous mixture of aluminum, babbitt, and other white metal and brass and bronze chips, which resembles aluminum only in its color, and which is of very little value to the founder. For example, two samples of metal offered for sale by one smelting company were analyzed by the foundry buying them, with the following results:

Composition of boring ingot made from various alloys.

	Sample A.	Sample B.
Copper.....per cent..	17.4	15.3
Zinc.....do....	8.4	6.7
Iron.....do....	1.8	2.0
Silicon.....do....	2.4	2.8
Manganese.....do....	0.5	Trace.
Aluminum.....do....	69.5	73.2

Samples of boring ingot from another company, sold as G. M. B. (good merchantable brand) metal, not as any standard alloy, analyzed by the buyer, gave results as follows:

Composition of G. M. B. metal.

Sample No.	Copper.	Zinc.	Iron.	Silicon.	Lead.	Tin.	Aluminum.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
C.....	6.4	25.0	1.0	0.3	1.9	1.3	64.1
D.....	6.8	6.0	0.7	0.2	1.3	0.6	84.4
E.....	7.5	5.6	0.8	0.4	2.0	1.0	82.7

Another sample (F) from this firm, sold as No. 12 boring ingot, analyzed by the buyer, contained 7.2 per cent copper, 3.9 per cent zinc, 1.5 per cent iron, 0.4 per cent silicon, no lead nor tin, and 87 per cent aluminum.

Samples of boring ingot from a third company (all sold on the seller's analysis), melted in crucibles in coke fires with NH_4Cl flux, had the following compositions:

Composition of boring ingot melted in crucible coke furnace with NH_4Cl flux.

Sample No.	Copper.	Zinc.	Iron.	Silicon.	Manganese.	Aluminum.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
G.....	4.2	2.5	9.3	0.6	1.2	82.2
H.....	3.9	12.1	3.0	0.5	0.15	80.35
I.....	7.3	4.3	1.5	0.4	.....	86.5
J.....	7.7	0.3	2.8	1.9	.....	87.3
K.....	8.8	0.75	2.0	1.0	.....	87.15
L.....	9.4	1.0	1.3	0.3	.....	88.0
M.....	7.7	0.3	2.8	1.9	.....	87.3
N.....	9.7	0.7	1.1	1.0	.....	87.5

Three samples taken from various parts of a quantity of boring ingot offered for sale by a fourth company, and analyzed by the buyer, had the following composition:

Composition of three samples of boring ingot.

Sample No.	Copper.	Zinc.	Iron.	Silicon.	Aluminum.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
O.....	7.9	2.0	0.6	0.4	89.1
P.....	7.8	0.4	.7	.4	90.7
Q.....	7.9	2.0	.7	.4	89.0

The results of buyers' analyses of various lots of No. 12 boring ingot sold by a firm using the iron pot, ZnCl_2 , puddling process, were as follows:

Composition of No. 12 boring ingot.

Sample No.	Copper.	Zinc.	Iron.	Silicon.	Aluminum.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
R.....	7.2	1.5	1.3	0.2	89.8
S.....	7.5	1.0	1.3	.3	89.9
T.....	7.6	1.5	1.5	.2	89.2
U.....	6.6	1.5	1.3	.2	90.4

Still another refining plant, using a reverberatory furnace and dealing with a mixture of No. 12 chips and emery grindings, has sold No. 12 boring ingot of the following composition, according to the buyer's analysis:

Composition of ingot from No. 12 chips and emery grindings.

Sample No.	Copper.	Zinc.	Iron.	Silicon.	Aluminum.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
V.....	7.3	2.4	1.3	0.2	88.8
W.....	8.6	0.4	1.1	.2	89.7
X.....	8.8	0.8	1.4	.4	88.6
Y.....	9.6	0.9	1.0	.4	88.1
Z.....	9.9	1.0	1.1	.3	87.7

The No. 12 alloy, made up from new metals, to contain 8 per cent copper, or purchased in market ingot made up from new metals, will analyze about 7.6 to 8.4 per cent copper, no zinc, 0.5 to 0.7 per cent iron, 0.25 to 0.4 per cent silicon, 91.65 to 90.5 per cent aluminum.

When melting in iron pots, about 0.2 per cent of iron is taken up from pots, ladles, and skimmers and about 0.05 per cent silicon from sand adhering to gates, making the average composition of the No.12 castings sold 7.6 to 8.4 per cent copper, no zinc, 0.7 to 0.9 per cent iron, 0.30 to 0.45 per cent silicon, and 91.4 to 90.25 per cent aluminum. This alloy comprises 90 to 95 per cent of all cast aluminum made in the United States.

EFFECT OF IMPURITIES.

The purity, or impurity, of boring ingot depends (1) on the purity of the castings from which the borings are made, (2) on the freedom of the borings from white metal, babbitt, or brass, (3) on their freedom from iron and on the efficiency of the magnetic separation, (4) on the presence or absence of dirt from which metals may be reduced, and (5) on the nature of the melting process and the temperature attained.

White metal, babbitt, brass, or bronze borings, if present, can not be efficiently separated from the aluminum borings and go into the melt. Copper, zinc, lead, tin, and antimony may come from these sources.

COPPER.

Of these metals copper is present not only in the No 12 alloy, but also in nearly all of the zinc-containing alloys, and its only bad effect would be to raise the copper content too high.

ZINC.

Zinc in No. 12 castings is frowned on by many purchasers, even if present only to the extent of a trace to less than one-half of 1 per cent, in some cases because it is known that zinc can not occur in No. 12 metal made wholly from virgin metal, but more often because a belief that the alloys of aluminum high in zinc give castings which may break in use under repeated shock is extended to the No. 12 alloy with but traces of zinc. This idea is prevalent in some sections of the country, whereas in other sections the zinc-containing alloys are much used. Alloys, such as the market "No. 31," containing about 3 per cent copper, 15 per cent zinc, 0.5 per cent manganese, 81.5 per cent aluminum, or a similar one containing 2 per cent copper, 19 per cent zinc, and 79 per cent aluminum, are stronger under tension or compression per unit weight than the No. 12 alloy, and, at normal prices for zinc, are cheaper per unit of weight or of volume. It does not appear to be satisfactorily proved that perfectly sound castings of these alloys are more likely to fail under repeated stress than the No. 12 alloy, as an alloy containing 19 per cent zinc has been satisfactorily used in one high-grade American automobile, and zinc-aluminum alloys, somewhat lower in zinc content, are used in European automobile plant practice almost to the exclusion of the No. 12 alloy, whereas the reverse is the case in the United States. It is claimed that because of the rougher roads in America the stresses a motor-car crank case, for example, has to endure are worse than in Europe, and that the zinc-containing aluminum alloys would not stand up as well as the No. 12 alloy under the more severe conditions in America. It is probable that the relative life of the crank cases

and other castings on the American and European motor cars and trucks in the European war will furnish some definite proof on this point.

It is true that it is more difficult to make complicated castings of zinc-containing alloys than of No. 12 alloy without having trouble from cracking in the mold, and that if castings with tiny cracks in them that have been undetected through lax inspection are put in service, failures are likely to result. But it is quite possible to make distinctly complicated castings of the zinc-containing alloys without defects if proper foundry practice is used.

Rosenhain and Archbutt ^a have made endurance tests of various aluminum alloys and do not find that the zinc-containing alloys are liable to fail under repeated shock. They indeed advocate the use of an alloy consisting of 20 per cent zinc and 80 per cent aluminum, or one containing 3 per cent copper, 25 per cent zinc, and 72 per cent aluminum, rather than those lower in zinc content, on account of the greater strength per unit weight.

A mixture of aluminum borings from various sources in the United States will consist mostly of No. 12 alloy, but may also contain some borings from alloys containing 10 to 30 per cent zinc, consequently the ingot from such mixed borings may contain zinc in varying amounts, as is shown by the analyses previously given.

As zinc volatilizes quite readily from aluminum alloys at the temperatures necessary in melting chips, some of the zinc content of alloys high in zinc will be lost in melting. A few hundredths of a per cent of zinc in No. 12 alloy might come from the taking up of zinc from $ZnCl_2$ used as a flux, whereas a few tenths of a per cent or more of zinc indicates that some scrap, or else No. 12 ingot made in part from scrap, has been used. There is no satisfactory evidence to show that a zinc content up to 0.5 per cent at least in No. 12 alloy is any detriment to the strength or endurance of the castings. As the presence of zinc indicates the presence of scrap and presumably of boring ingot which may, under conditions not clearly understood, give rise to the cracking of castings in the mold or to other foundry defects, some progressive founders are using virgin pure aluminum and copper and preparing their own No. 12 alloy instead of purchasing the prepared alloy, and are using analyzed boring ingot in varying proportions, or leaving it out altogether, according to the liability of the individual casting that is to be poured from the metal to the troubles which boring ingot sometimes causes. With such rational utilization of boring ingot it finds a legitimate use in the foundry.

^a Rosenhain, W., and Archbutt, S. L., Alloys of aluminum and zinc: Engineering, vol. 93, 1912, p. 579.

LEAD.

Lead is not a desirable constituent in aluminum alloys, as it does not alloy with aluminum, but is merely inclosed in small globules. The lead, on account of its high specific gravity, will tend to collect at the bottom of the casting, and any appreciable amount tends to weaken the alloy. Such boring ingot as that shown by analyses C, D, and E is of poor quality on account of the lead content.

TIN.

Tin is to be classed as a less harmful impurity. It tends to soften the alloy without noticeably affecting the strength. A small producer of high-grade automobiles has used an alloy containing 5 per cent copper and 3 per cent tin without any apparent disadvantage save a slightly lower strength. Such an alloy made from new metals has no obvious advantage to counterbalance the high cost of the tin, but a few tenths of a per cent of tin is not to be feared in boring ingot, save that, as it usually comes from admixed solder or from bronze chips, it may be accompanied by lead.

ANTIMONY.

The effect of antimony on aluminum alloys is not well known. Its occurrence in boring ingot would indicate admixture of babbitt with the chips.

MANGANESE.

Manganese in appreciable proportion would indicate that the ingot was made from material containing more or less hard sheet clippings. In small amount, with a high zinc content, for example, in analysis H, it would indicate that the mixture melted contained some No. 31 alloy chips.

In percentages up to say 0.2 per cent, manganese is not a detriment to No. 12 alloy, and some founders think that 0.1 or 0.2 per cent is distinctly desirable, although manganese is seldom intentionally added to No. 12 alloy, its source being some form of scrap from hard-sheet aluminum.

IRON.

Iron is the main impurity in boring ingot made from No. 12 chips and comes from the admixture in the machine shop of iron or steel chips with the aluminum chips. Commercial magnetic separation of iron from such chips may leave, especially in the case of very oily chips, 0.5 to 1.0 per cent of free iron in the mass. All of this free iron goes into solution when the mass is melted. Save for the free iron, no increase in iron content would be shown in melting chips in crucibles and not over 0.25 per cent increase in melting in iron pots by the puddling process.

INTERRELATED EFFECTS OF IRON, COPPER, AND ZINC.

As high as 2 per cent of iron in the No. 12 alloy would probably give too brittle an alloy, but a content of between 1 and 1.5 per cent does not appear to have a notably detrimental effect. If the iron content rises above 1 per cent, the copper content should be correspondingly reduced below 8 per cent in order to prevent brittleness, as iron acts much like copper in hardening and strengthening aluminum.

Cast No. 12 alloy, unannealed, consists of a needle-like CuAl_2 -Al eutectic embedded in the groundmass of solid solution of copper in aluminum. Iron in aluminum causes a similar needle-like structure in a groundmass of solid solution, and as the properties of the No. 12 alloy depend largely on the proportions of needles and groundmass too high an iron content will give too much of the needle-like material. If zinc be added to the No. 12 alloy, more of the needle-like eutectic is thrown out than without it, so that in the commercially useful ternary alloys of copper, aluminum, and zinc the copper is used in smaller amount as the zinc is used in larger amount. For example, an alloy containing 7.5 per cent copper and 1 per cent zinc has about the same tensile strength and elongation as one containing 8 per cent copper. With 20 per cent zinc not over 4 per cent copper and with 30 per cent zinc not over 2 per cent copper should be used, else too brittle an alloy will result.

By proper reduction in the copper content the effect of high iron content and of a little zinc, introduced by the use of some boring ingot, can largely be neutralized, and the resulting alloy will still have very closely the properties of No. 12 alloy as regards foundry behavior, shrinkage, and tensile strength and elongation.

SILICON.

Silicon is generally considered to be an undesirable impurity and, especially if in the form of graphitic silicon, to be conducive to brittleness. It is always present in small amount in commercial aluminum, owing to the difficulty of completely freeing from silica the bauxite used in its manufacture.

In remelting gates to which molding sand adheres, or in melting chips that contain siliceous dirt some silica may be reduced to silicon which alloys with the aluminum and an equivalent amount of aluminum is oxidized and lost.

This reduction of silica by aluminum is not marked below 800°C . and even when melting in fire clay graphite crucibles only a very small content of silicon is taken up if the temperature is kept low. As the temperature increases reduction takes place more readily, so that at the temperatures necessary in melting chips some slight in-

crease in silicon content is to be expected if they contain siliceous dirt. The use of a flux that will dissolve or soak up the dirt and so take it out of contact with the metal might be expected to decrease the amount of silicon taken up at any given temperature.

The results of analyses of commercial lots of boring ingot as shown on pages 73 and 74 give no information as to the relative purity of ingot made from the same lot of chips by different methods of melting, as any such differences are doubtless overbalanced by variations in the purity of the alloys from which the chips were taken and by variations in the content of free iron and dirt.

COMPOSITION OF INGOT FROM ELECTRIC FURNACE.

Analyses were made by the writers of the ingot obtained in the 15-pound melts of chips from lot B in the electric crucible furnace, in run 69 when a yield of 58 per cent on the original weight of the borings was obtained with sal ammoniac flux, in run 70 when a yield of 71.5 per cent on the original weight was obtained with NaCl-CaF₂ flux, and in run 83 when a yield of 89 per cent was obtained with the NaCl-CaF₂ flux on the fraction over 14-mesh in size. The results of the analyses were as follows:

Composition of ingot from melts in electric furnace.

Run No.	Copper.	Iron.	Silicon.	Manganese.	Zinc.	Aluminum (by difference).
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
69	7.40	1.87	0.34	Trace.	None.	90.39
70	7.39	1.92	.36	Trace.	None.	90.33
83	7.42	1.25	.34	Trace.	None.	90.99

The only appreciable difference is in the lower iron content of the fraction over 14-mesh, which indicates that most of the free iron left in this sample after commercial magnetic separation was under 14-mesh, an assumption which is corroborated by visual examination. Notwithstanding the difference of 13.5 per cent in the yields of runs 69 and 70, the composition of the ingot obtained is identical. As the run with the salt and fluorspar flux shows no appreciable increase in silicon content although the borings contained over 12 per cent of siliceous dirt, and as, unless the borings are melted in an iron pot, the iron content can not be greater than the original content in the alloy from which the chips were made plus the free iron not removed by the magnetic separator, the criticism that the high temperature needed to make this flux fluid results in ingot higher in impurities than by other methods of melting does not seem well founded.

NECESSITY FOR CARE AND CLEANLINESS IN COLLECTING CHIPS.

The high loss in melting chips caused by difficult coalescence and subsequent oxidation of globules entangled in the dross, and the poor quality of boring ingot are due primarily to lack of care and cleanliness in the collection of the chips in the machine shop. If the aluminum chips are kept free from brass, bronze, solder, white-metal, or iron chips, and also free from dust and floor sweepings, the only foreign material in them will be the cutting oil or cutting lubricant. By promptly centrifuging the chips these lubricants can be removed and recovered, and the chips left in a better condition for melting. If chips are thus collected and centrifuged and then stored in covered receptacles so that dust can not settle on them, clean chips will result.

The value of clean chips is so much greater than that of dirty chips, mixed with iron chips, that the slight increase in cost of careful collection over that of collecting by slipshod methods would be many times repaid and on the large amount of chips produced by even a comparatively small manufacturer of motor cars the saving would be well worth while.

As at least two methods of melting chips now in use by refiners, the puddling process and the NaCl-CaF_2 process, will give a recovery of 90 per cent or higher on absolutely clean chips and produce boring ingot of good quality, the responsibility for the waste of aluminum in melting chips, which is large in the aggregate, rests at the door of the machine shop that permits iron and dirt to get into the chips, rather than at the door of the foundry or refining plant that attempts to turn the chips into usable ingot.

Foundry refuse, such as buttons recovered from skimmings can not, in the nature of the material, be collected free from foreign matter. Hence such material, as well as carelessly collected chips, offers difficulties in melting owing to reluctance of the globules formed in melting to coalesce.

PROBABLE RELATIVE USEFULNESS OF DIFFERENT MELTING METHODS.

Of the methods suggested for melting aluminum chips, some are of doubtful practicability. Feeding the chips into the molten electrolytic bath used for producing pure aluminum is plainly useless in the case of dirty chips, on account of fouling the rather expensive electrolyte. The method is not well understood by founders and refiners, as the details of the electrolytic process are kept secret by the producers of aluminum, so that even on clean chips the method would be of use only to those producers.

Briquetting involves the use of expensive machinery, and although the use of briquets might slightly decrease the melting loss, would probably materially decrease the melting time and fuel cost, and would certainly increase the ease of handling, yet it is likely that a briquetting machine of the type necessary to produce solid briquets would have to be kept in constant use in order that the interest on the first cost should not eat up the savings.

Hence briquetting would only be practiced by large refiners who have large amounts of aluminum chips to handle or have other uses for such apparatus. Even at such plants the question whether briquetting would pay is not yet fully answerable, although the process deserves serious consideration.

The use of electric furnaces, vacuum furnaces, retorting furnaces, or other devices which merely prevent the access of air without providing for the promotion of coalescence by stirring seems to offer little promise.

The method so often advocated of pushing the borings beneath a heel of molten metal seems to owe any usefulness it may have to the pushing and not to the heel. It is an approach to the puddling process, which seems to be the best modification of the scheme.

In the iron-pot puddling process, which is evidently of much value on clean borings, the vital points are to keep the temperature very low, practically at the melting point, to prevent oxidation, and constantly stir the pasty mass to promote coalescence. The process requires constant hand labor, does not seem as useful on very dirty borings, and could hardly be applied to large units.

Possibly some mechanically stirred furnace, or one in which pressure was constantly applied, analogous to the Côte and Pierron suggestion or to the Montefiore method for melting blue powder, could be devised that would have the advantages of the puddling process without the high labor cost, but no such apparatus had yet been put forth, and the making of one that would have a low upkeep cost presents serious difficulties.

The use of volatile fluxes such as sal ammoniac and zinc chloride is of advantage at the end of the puddling process, but melting with these fluxes without constant stirring gives very low recoveries.

The use of fluxes that form molten covers seems to be of real advantage only when rather large quantities of the flux are used, and the promotion of coalescence by the flux soaking up dirt and oxide seems to be of more importance than the prevention of oxidation by exclusion of air. Although fluxes melting at or below the melting point of aluminum are theoretically preferable to those of higher melting point, it is difficult to find such low-melting fluxes chemically inert to aluminum without using mixtures containing materials such as

lithium chloride or potassium chloride, the first of which is very costly and the second relatively so, or hygroscopic materials such as calcium or magnesium chlorides. Common salt, the cheapest flux of the molten-cover type, seemingly gives the best results, when the cost and convenience of the flux is considered. Still better are fluxes that have a real solvent action on aluminum oxide and on dirt in general, such as the mixtures of alkali chlorides and fluorides. With such fluxes better absolute recoveries could probably be obtained by using very low melting mixtures, but as large amounts of these fluxes are necessary their cost is prohibitive, and the cheap flux consisting of 85 parts common salt and 15 parts fluorspar, used in large amounts, 20 to 30 per cent of the weight of the chips, mixed with the chips before charging, and the whole heated in crucibles till the flux is fairly fluid, seems the most useful. On clean borings it would probably not give higher results than the iron-pot puddling process, but it may be preferable even then as constant stirring is not required, and thus the labor cost would be less, and because it might make large-scale reverberatory melting feasible. The experiments on reverberatory melting indicated this possibility but were on too small a scale to be conclusive. If chips must be melted in pit fires, the flux method is the most suitable; if iron-pot furnaces are to be used, the puddling process is the better.

There is also a possibility that dirty borings washed with dilute caustic soda, subjected to wet concentration, as on Wilfley tables, and then dried by centrifuging, would yield a clean product on which the melting loss would be low. Lack of suitable apparatus made the actual experiments inconclusive, but the scheme seems worthy of a trial on a commercial scale.

However, if the machine shops producing aluminum chips would keep the borings clean and free from contamination, it would not be necessary to go to the expense of removing foreign matter.

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PUBLICATIONS ON MINERAL TECHNOLOGY.

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